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Geography's Unique Role in Climate Change Policy Analysis

From Global Mitigation to Regional Renewable Energy Development to Local Adaptation Strategies

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Publication date:
2012

Document Version
Publisher's PDF, also known as Version of record

Geography's Unique Role in Climate Change Policy Analysis: From Global Mitigation to Regional Renewable Energy Development to Local Adaptation Strategies

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23 Jan 2012

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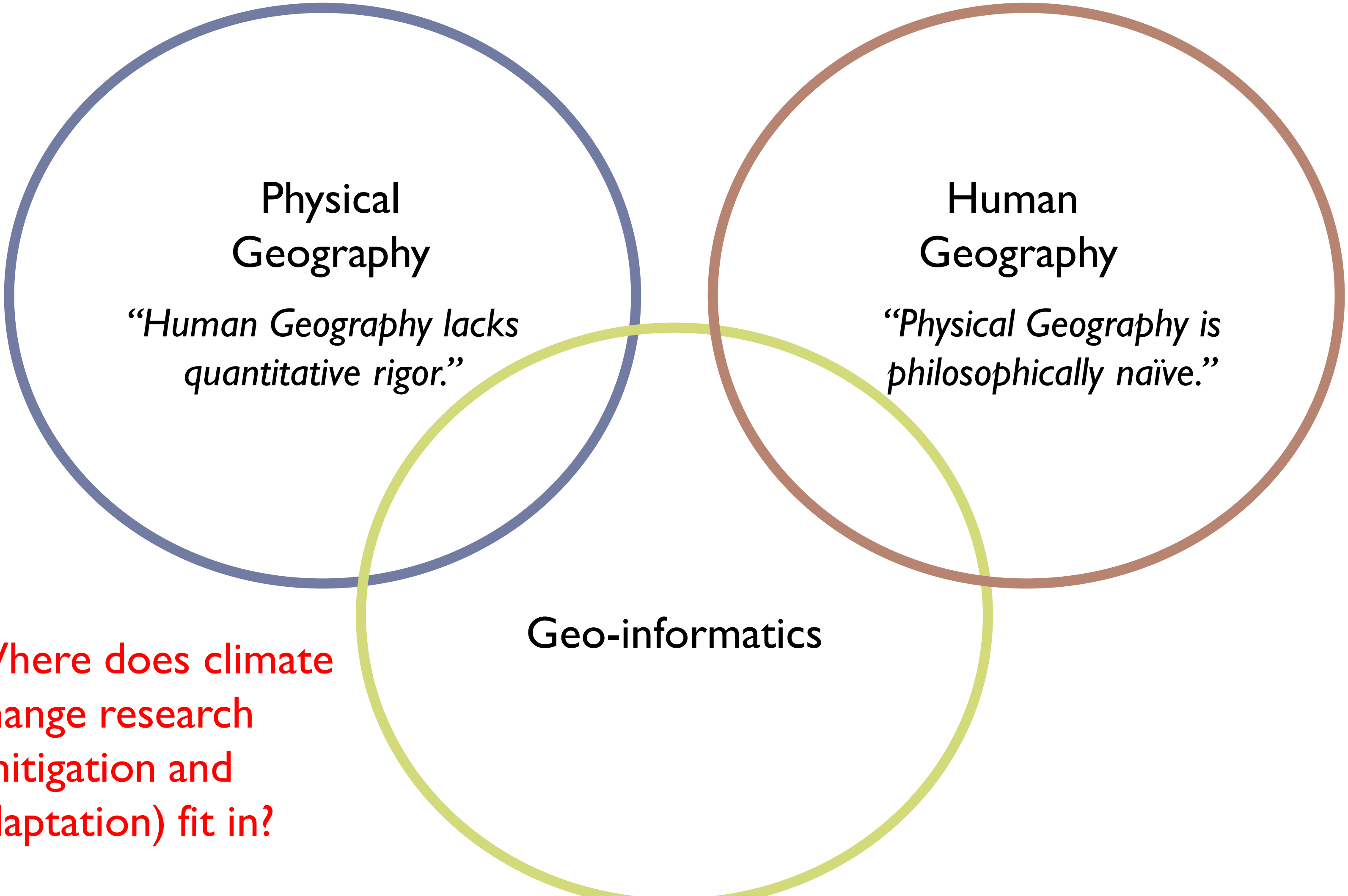
Geography

"Geography is the study of earth as the home of people."

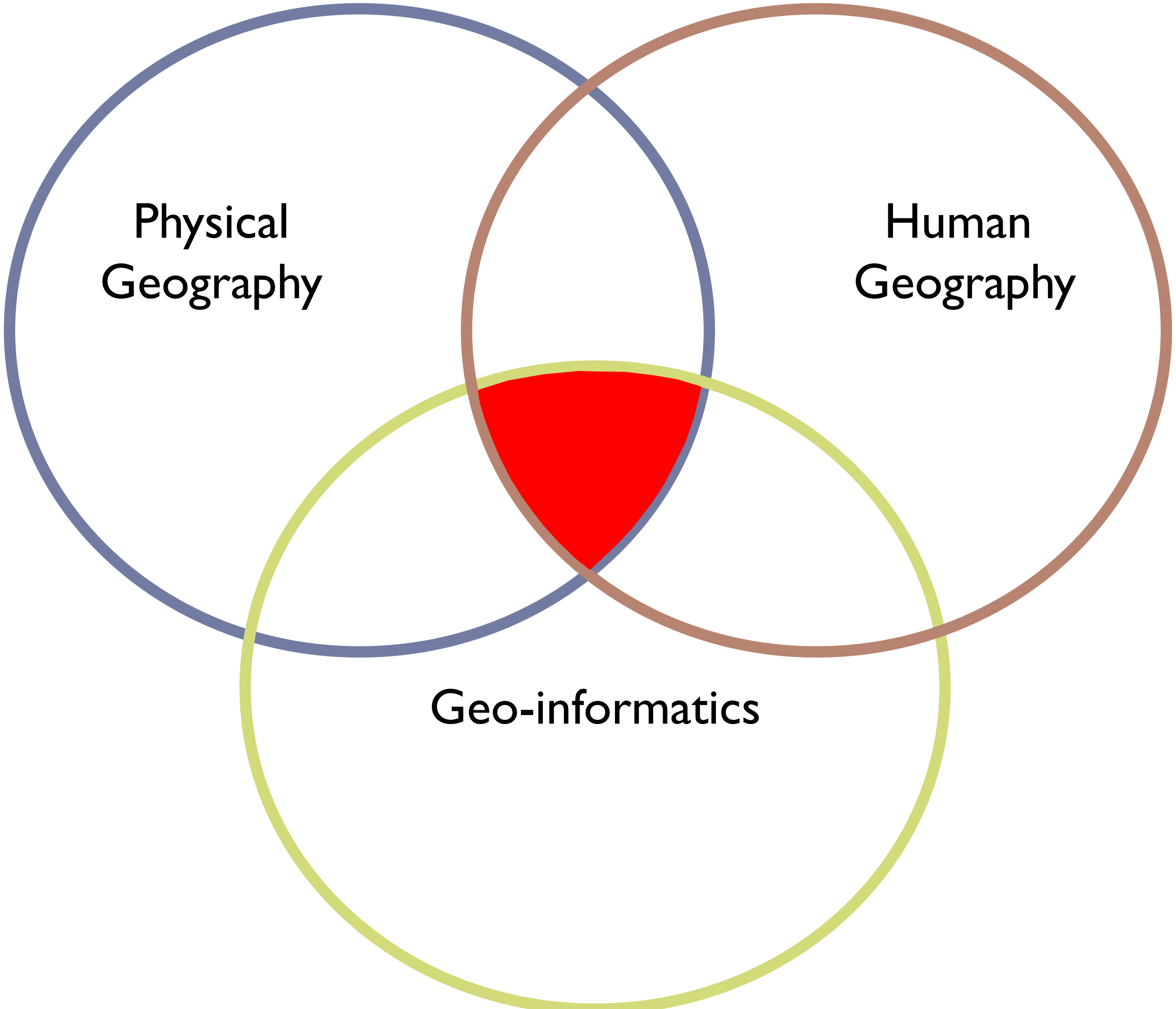
Yi-Fu Tuan, 1991

Geography



Where does climate change research (mitigation and adaptation) fit in?

Geography



Geography and Climate Change

- Humans are influencing the physics and chemistry of Earth's climate

  "Most of the observed increase in global average temperatures since the mid-20th century is very likely *due to the observed increase in anthropogenic greenhouse gas concentrations."* - IPCC AR4

- Humanity is sustained by constrained by the physical system.

  "The human mind, so frail, so perishable, so full of inexhaustible dreams and hungers, burns by the power of a leaf." - Loren Eisley, Anthropologist

- Understand these relationships requires constant monitoring and sophisticated spatial tools.

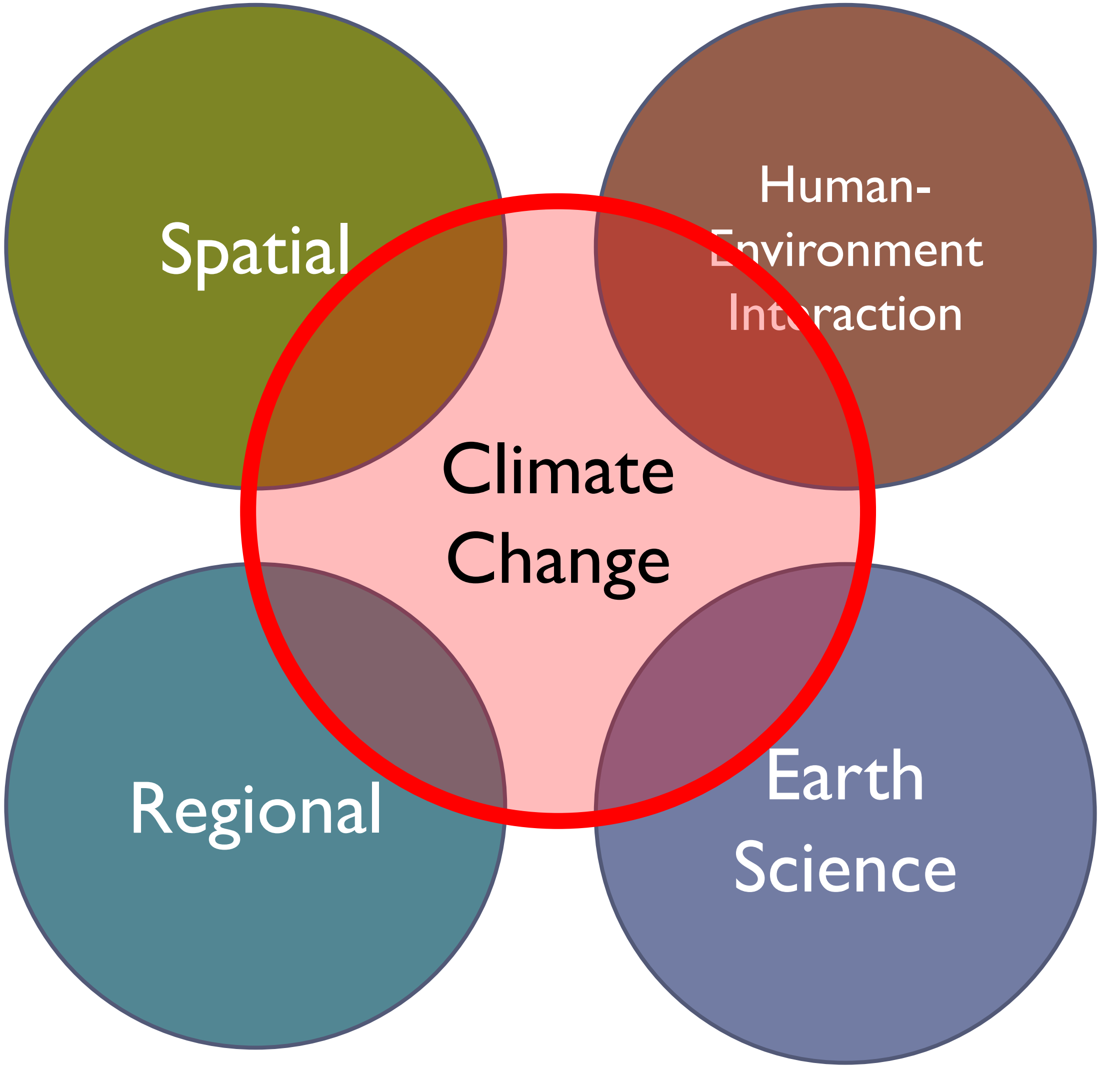
  "Climate change is a geographic problem, and we believe solving it takes a geographic solution. GIS users represent a vast reservoir of knowledge, expertise, and best practices in applying this cornerstone technology to the science of climate change and understanding its impact on natural and human systems."- Jack Dangermond, founder of ESRI

Geography and CC

4 Geographic Traditions
William D. Pattison, 1963

What is driving climate change, where are the resources, where are the potential, where are the impacts?

What is the link between the economy, energy, and the environment? What are the social drivers to CC?



Which regions are impacted by CC? How will they respond and adapt?

Where are the physical linkages in the Earth System? What is the climate sensitivity?

Climate Change Research

- What should we do?

"Are you saving the world, or just tracking its slow, steady destruction?"

This is a normative question; a question of science-informed policy

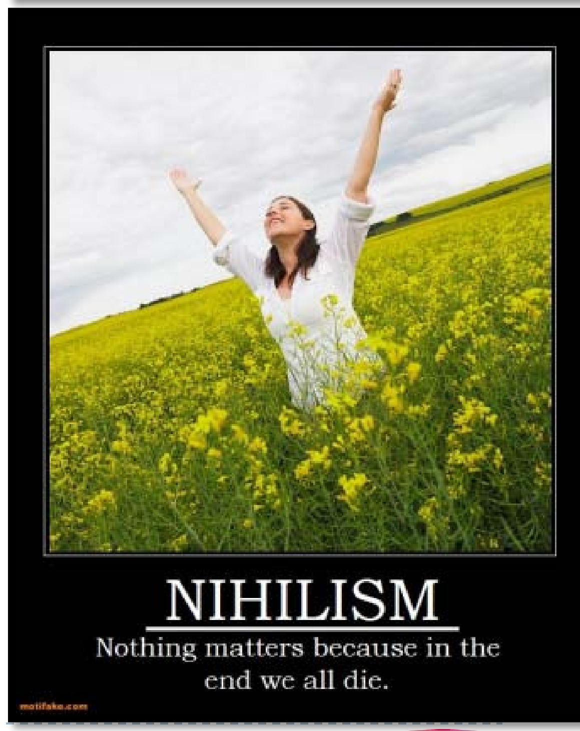
- 1. Mitigation: Create an international policy to reduce greenhouse gas emissions
- 2. Low Carbon Energy Development: Replace fossil fuels with climate friendlier alternatives
- 3. Adaptation: Build more resilient societies to lessen the impacts from climate change

Differences between physical science and policy analysis

For policy analysis to make sense, we have two philosophical assumptions:

1. **Non-Determinism:**
   If we assume that whatever is going to happen is already predestined, then policy has no role. We have to assume that policy has the power to change the course we are on.

2. **Non-Nihilism:**
   We have to assume that some outcomes are better than others and that there exists a criteria for deciding between the different outcomes. If not, policy again would have no purpose because every possible future would be equally desirable.



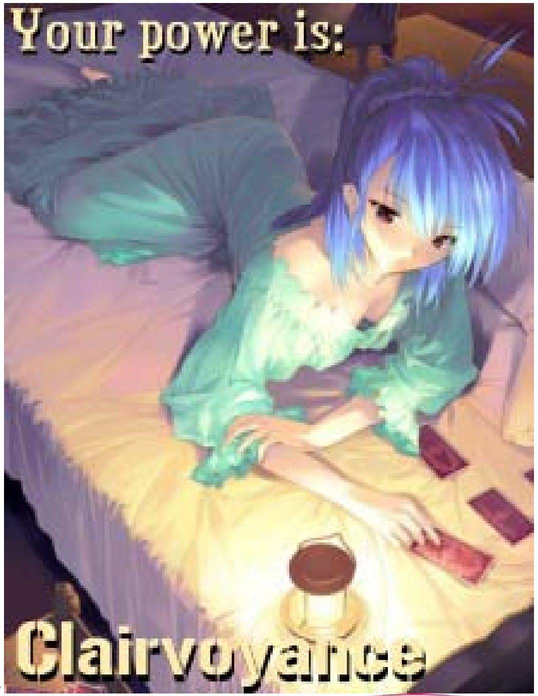
The Time Dimension

- How do we represent future hypothetical states and risk in models?
- How do we model future human behavior on a societal level?
- How do we know what future generations will value?
- What is the role of policy *vis-a-vis* climate change?
- Humans make decisions and act; we are a dynamic and non-deterministic system

Science and Policy Analysis

- Challenges of modeling the future (validation):
  - Is it possible for a model to predict the future in a human system?
  - Is it possible to test the model by running from a past date to the present?

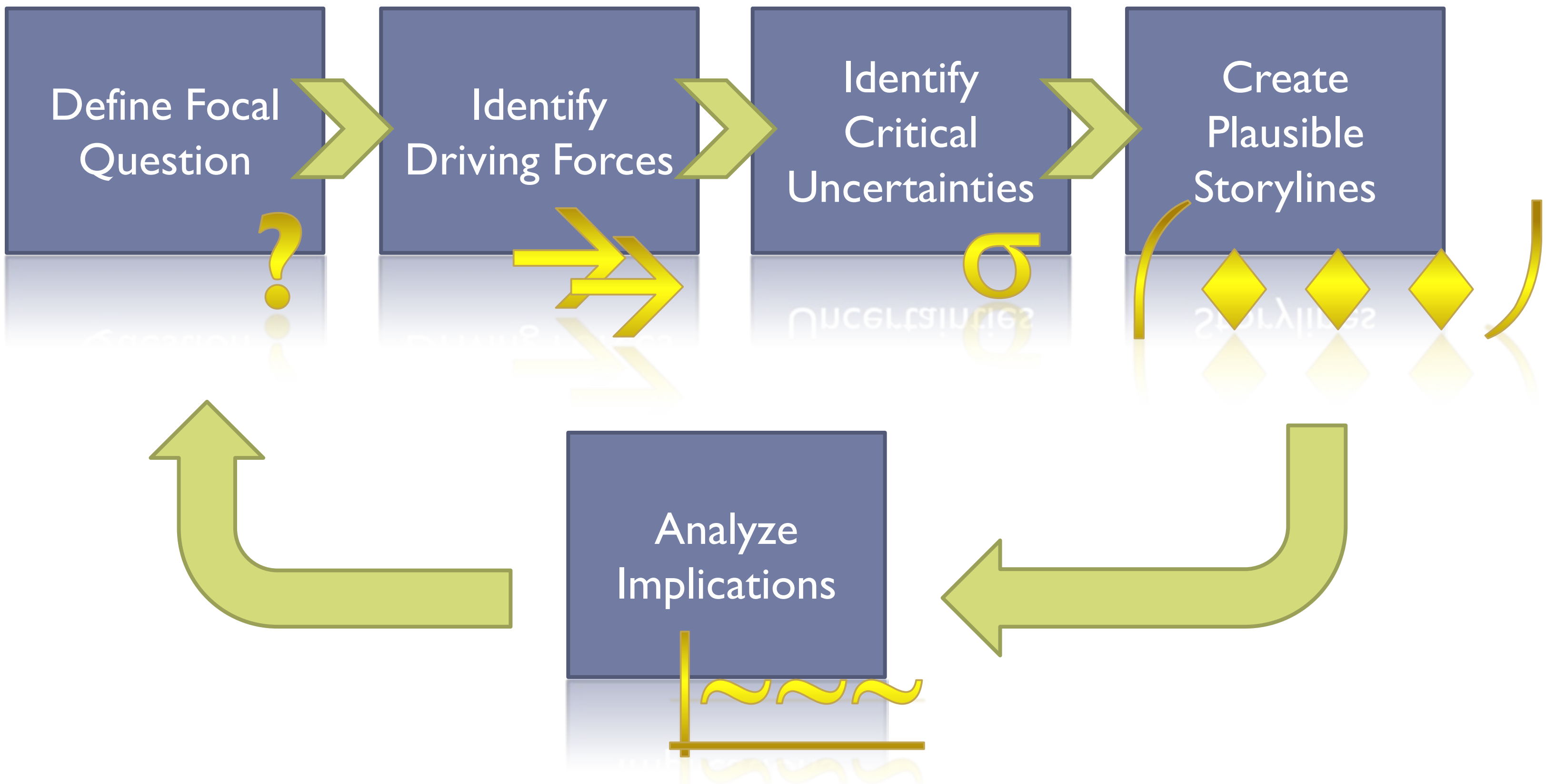
No!



Studying the Future: A Science of Scenarios

- **Not predictions or forecasts for the future!**
  - Rather, plausible storylines and hypothetical futures
- Bracket sets of outcomes- sensitivity
- Answer specific questions, holding constant a set of assumptions
- Allow for strategic planning and decision making when facing uncertainty
- "Climate scientists have become, *ipso facto*, social scientists." (Wainwright, 2010)

Scenario Development Process



Science and Policy Analysis

- How do we avoid "dangerous climate change" in the most economically efficient way?
- How important is a technology or resource in addressing climate change, sustainable development, and energy security relative to other options?
- What are the extent of anticipated climate change impacts and the potential effectiveness of adaptation measures?

Example Questions from Scenario Analysis

- How do we avoid "dangerous climate change" in the most economically efficient way?
- How important is a technology or resource in addressing climate change, sustainable development, and energy security relative to other options?
- What are the extent of anticipated climate change impacts and the potential effectiveness of adaptation measures?
- ~~What will be the value of the Euro in 2050?~~
- ~~Where will resource conflicts occur in the future?~~
- ~~Who will win the EuroCup?~~

Outline

- 0. Geography within Climate Science and Policy Analysis
- 1. Climate Change Mitigation
- 2. Renewable Energy Potential: Municipal Residue Biomass
- 3. Climate Change Impacts, Adaptation, and Decision Making

Part 1.
Climate Change Mitigation

How do we avoid "dangerous climate change" in the most economically efficient way?

Integrated Assessment Models (IAMs)

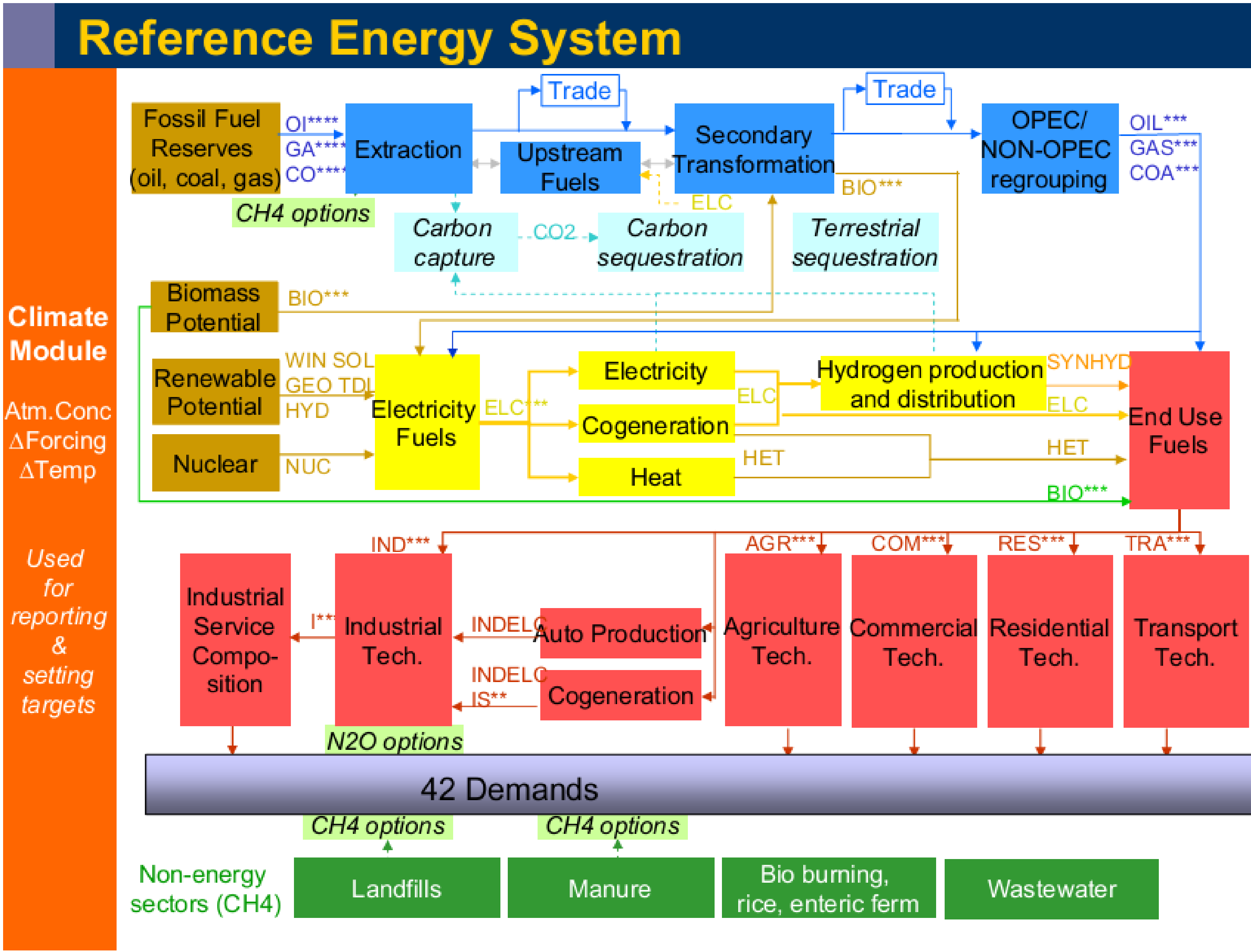
- Interdisciplinary (Integrated)
- Policy Relevant (Assessment)
- Tradeoffs between completeness vs. complexity (Modeling)
- Global and long-term (Climate change)
- Economic Optimization (Aggregate human drivers)

Integrated Assessment Models (IAMs)

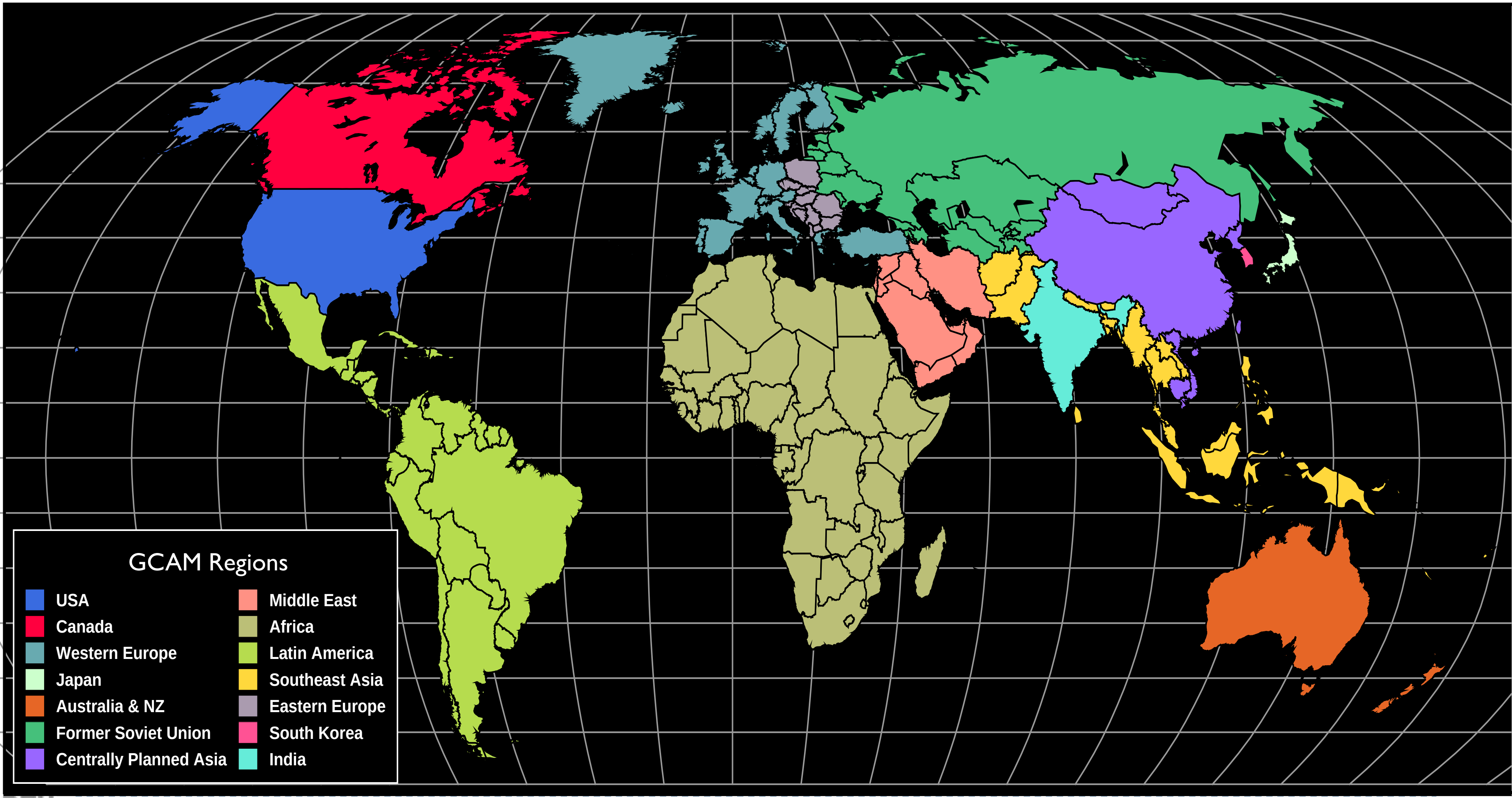
- Framework for understanding climate change, taking into account economics, demographics, policy, technology, and other human factors.
- Regional information on population, economy, energy demand, resources
- Different policy scenarios and market dynamics.
- Built in climate model built in that can estimate GHG concentrations, radiative forcing, temperature, sea level rise, etc.

TIAM: TIMES Integrated Assessment Model

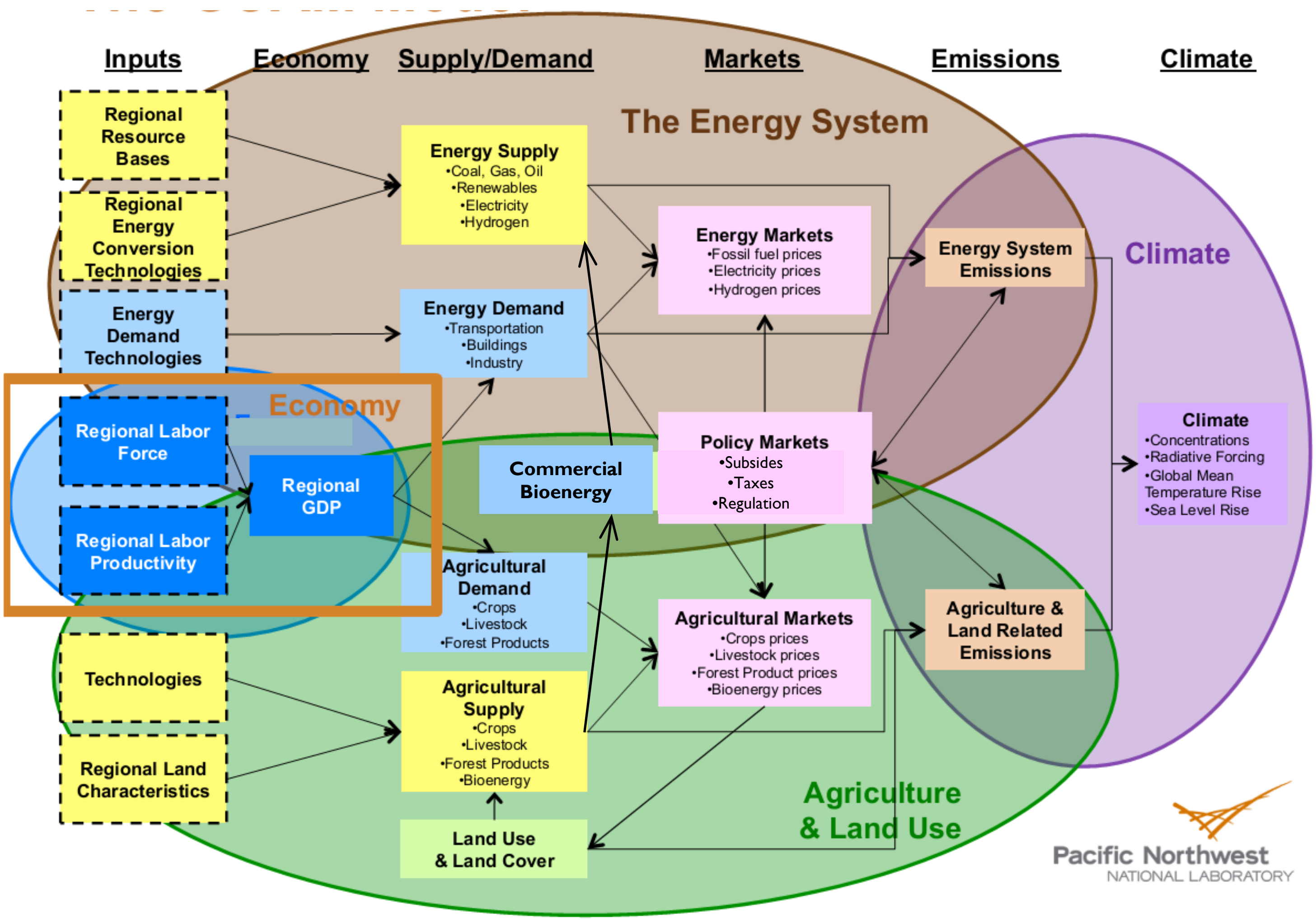
IAM Structure example: TIAM



GCAM: Global Change Assessment Model



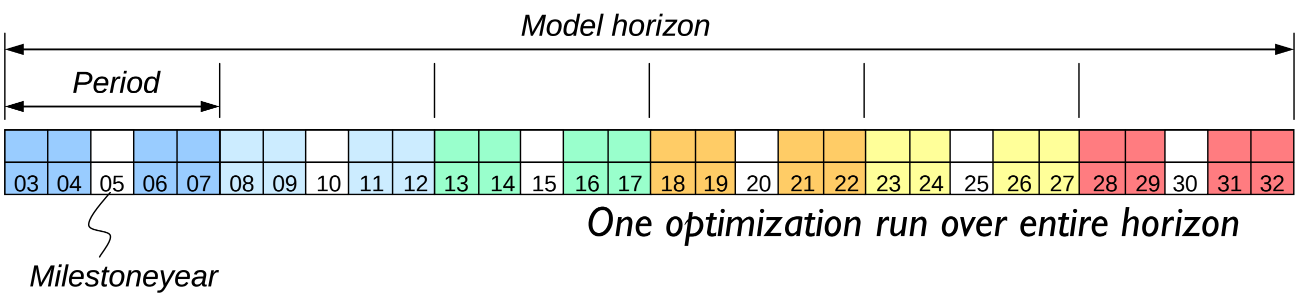
IAM Structure Example: GCAM



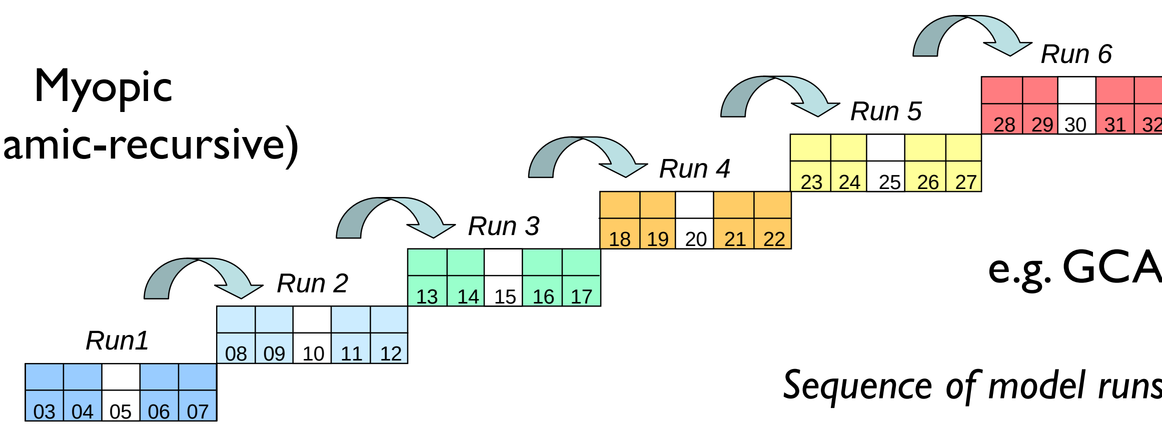
IAM Economic Optimization

Perfect foresight
(Inter-temporal optimization)

e.g. TIAM



Myopic
(Dynamic-recursive)



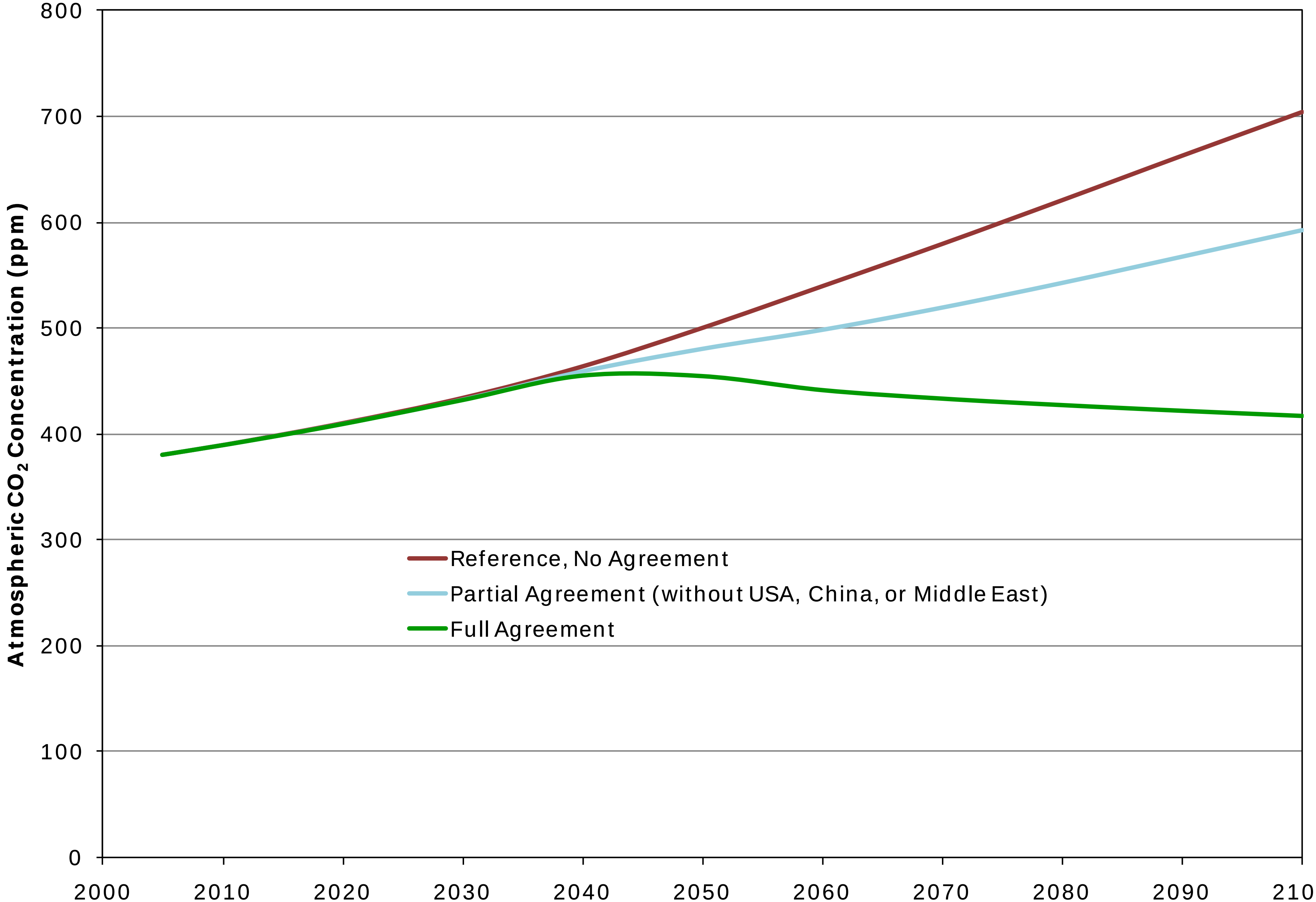
e.g. GCAM

Analyzing Possible Climate Policy Regimes

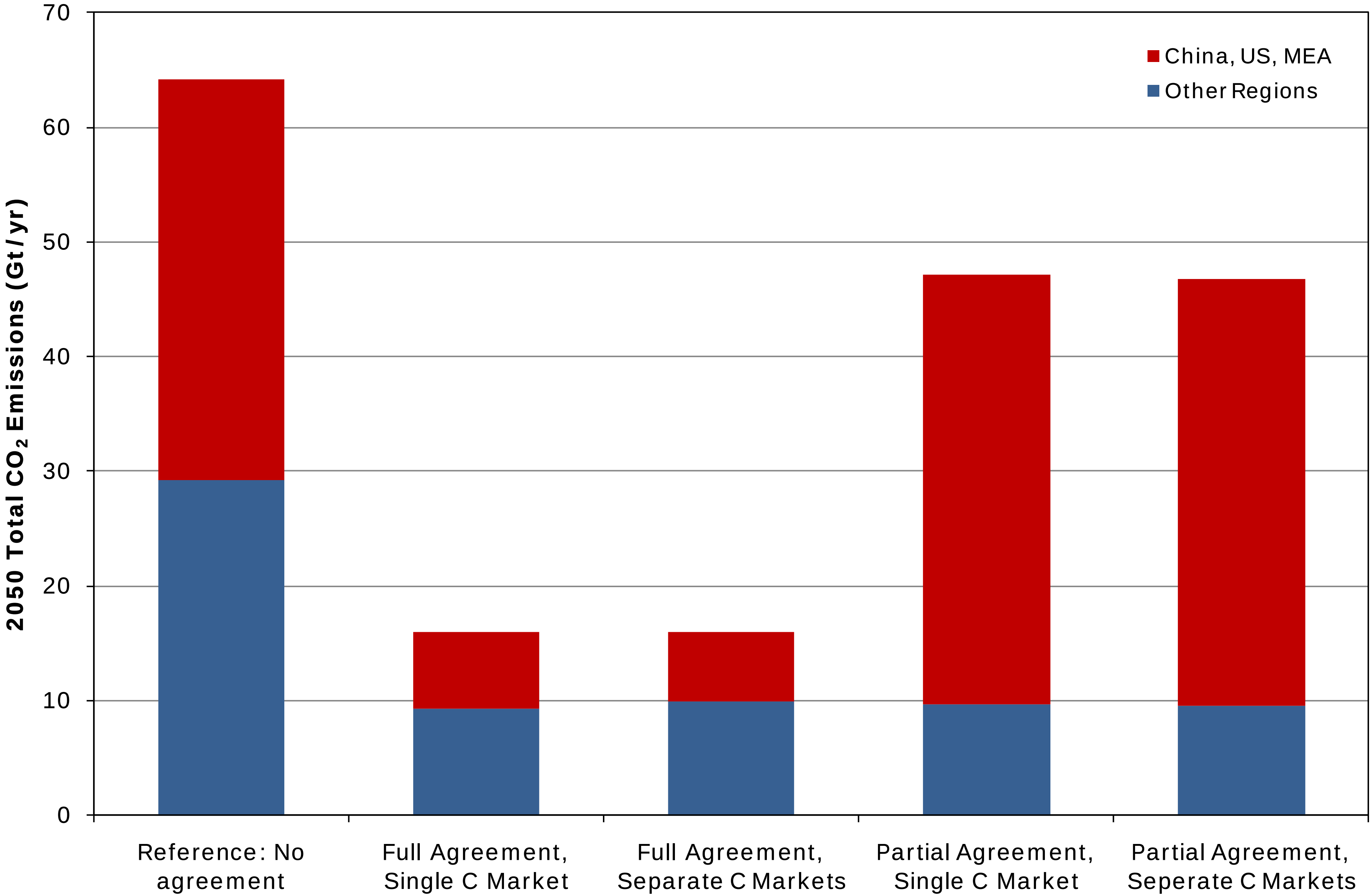
- What is the effect of a global policy versus partial agreement?
- What is the effect of multiple carbon markets?

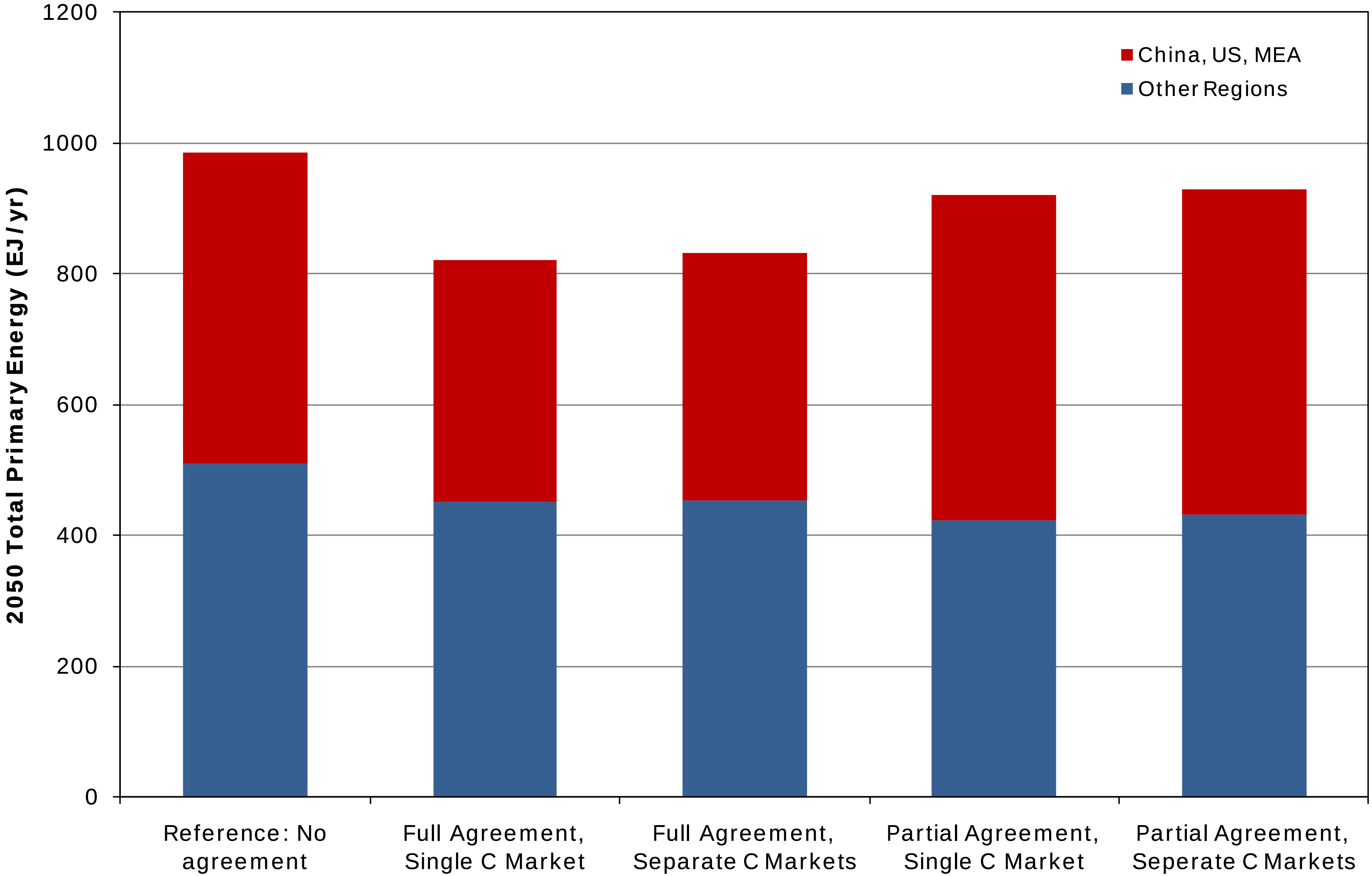
5 Scenarios:

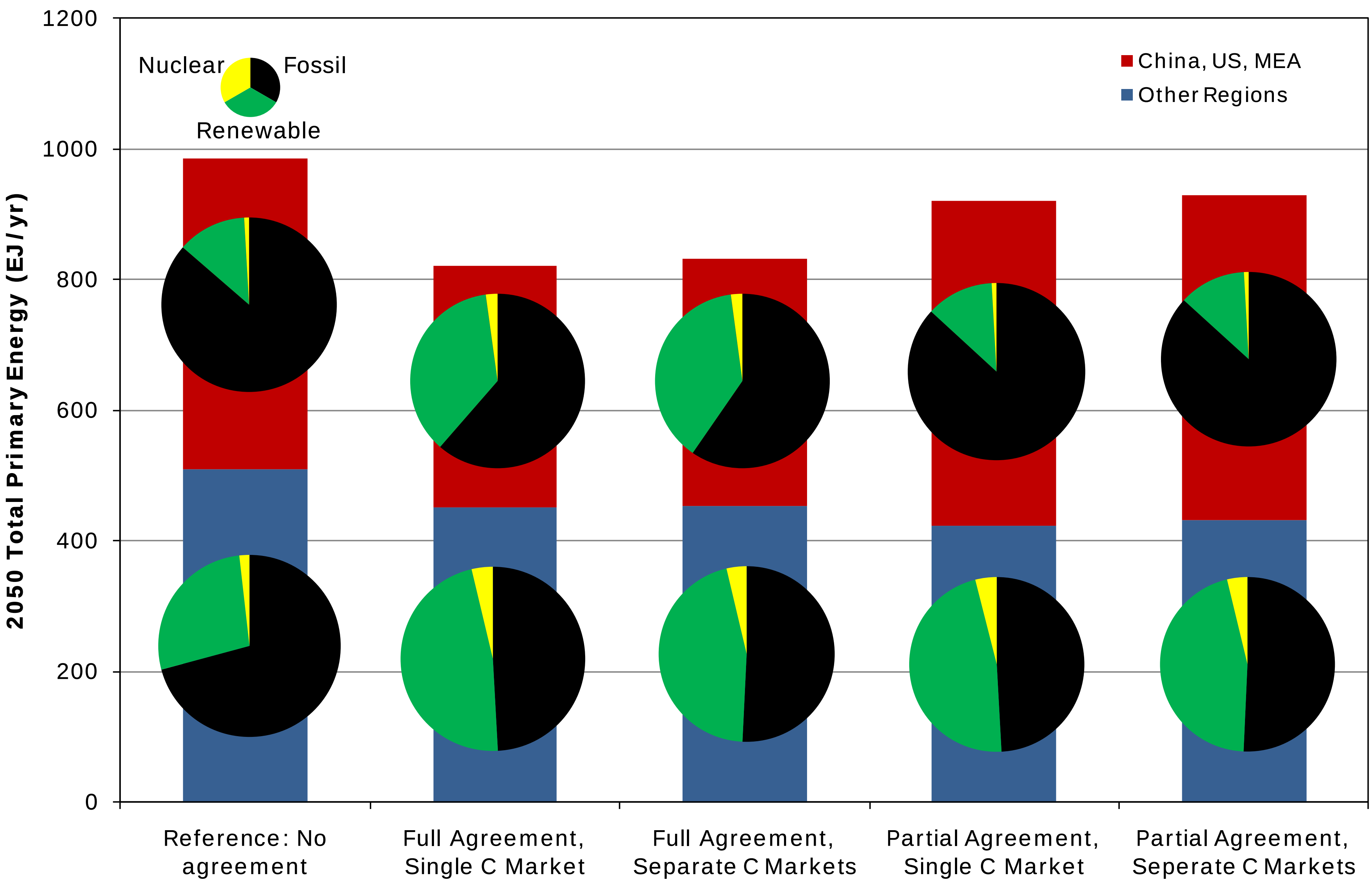
1. Reference (no price for carbon)
2. Full agreement, single global carbon market
3. Full agreement, two carbon markets
   (developed, developing world)
4. Partial agreement, single carbon market
5. Partial agreement, two carbon markets
   (developed, developing world)



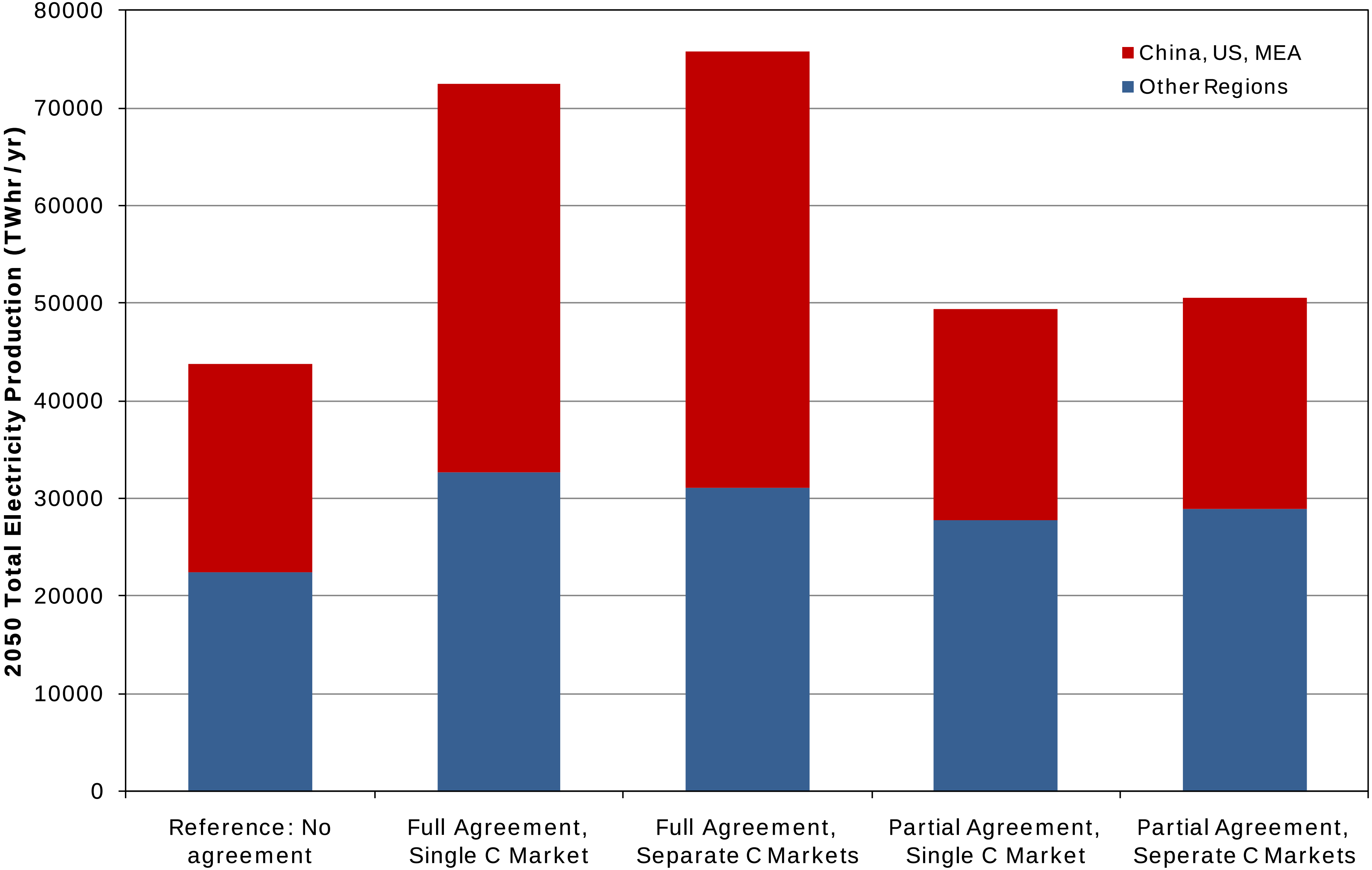
800
700
600
500
400
300
200
100
0
Atmospheric CO2 Concentration (ppm)
2000
2010
2020
2030
2040
2050
2060
2070
2080
2090
2100
Reference, No Agreement
Partial Agreement (without USA, China, or Middle East)
Full Agreement


China, US, MEA
Other Regions
2050 Total CO_2 Emissions (Gt / yr)
0
10
20
30
40
50
60
70
Reference: No agreement
Full Agreement, Single C Market
Full Agreement, Separate C Markets
Partial Agreement, Single C Market
Partial Agreement, Seperate C Markets

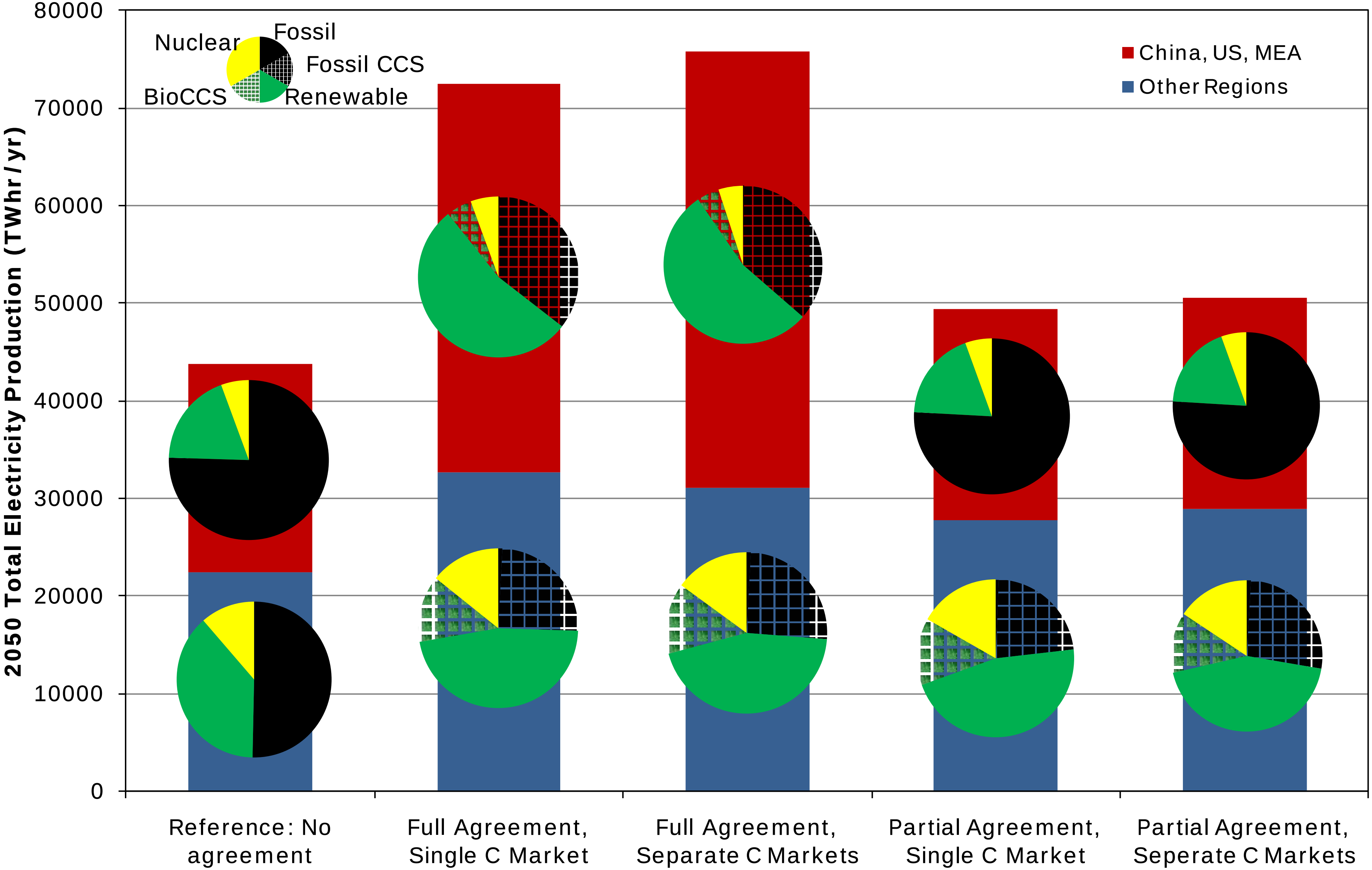

1200
1000
800
600
400
200
0
2050 Total Primary Energy (EJ / yr)
China, US, MEA
Other Regions
Reference: No agreement
Full Agreement, Single C Market
Full Agreement, Separate C Markets
Partial Agreement, Single C Market
Partial Agreement, Seperate C Markets



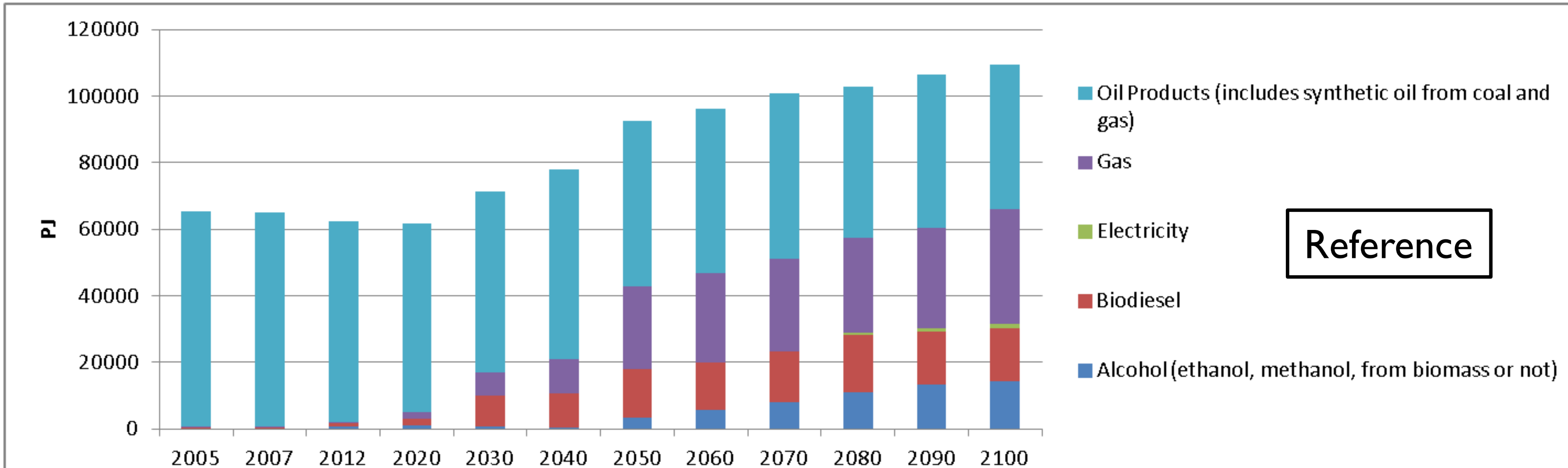
2050 Total Primary Energy (EJ / yr)
1200
1000
800
600
400
200
0
Nuclear
Fossil
Renewable
China, US, MEA
Other Regions
Reference: No agreement
Full Agreement, Single C Market
Full Agreement, Separate C Markets
Partial Agreement, Single C Market
Partial Agreement, Seperate C Markets

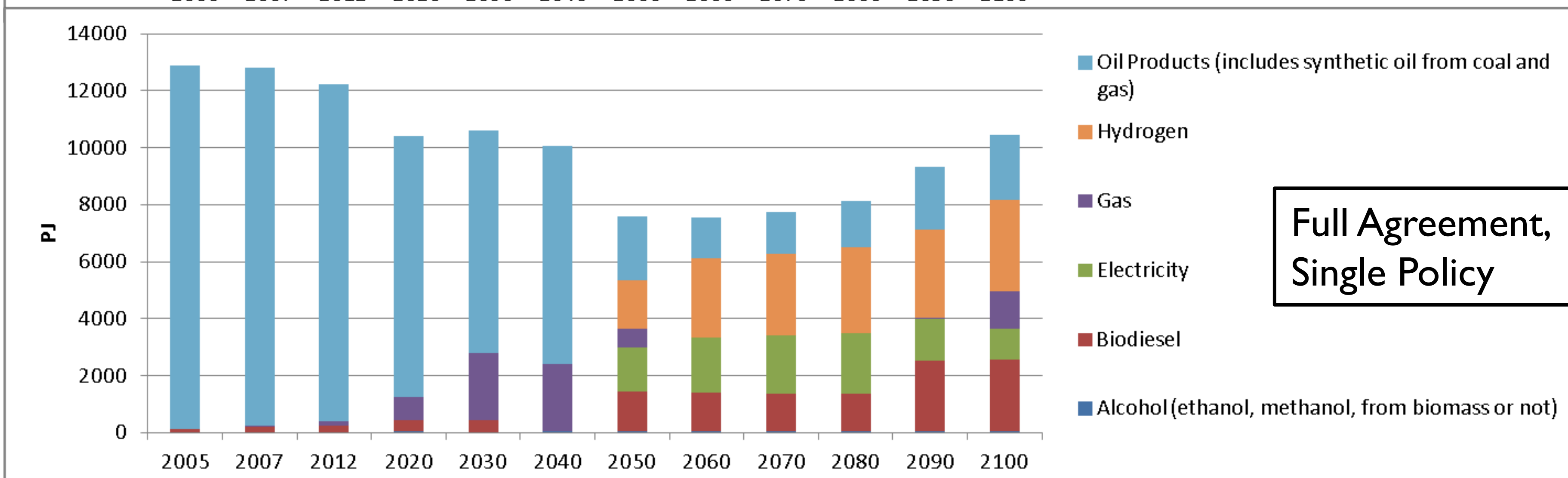


2050 Total Electricity Production (TWhr / yr)
80000
70000
60000
50000
40000
30000
20000
10000
0
China, US, MEA
Other Regions
Reference: No agreement
Full Agreement, Single C Market
Full Agreement, Separate C Markets
Partial Agreement, Single C Market
Partial Agreement, Seperate C Markets


80000
70000
60000
50000
40000
30000
20000
10000
0
2050 Total Electricity Production (TWhr / yr)
Nuclear
Fossil
Fossil CCS
BioCCS
Renewable
China, US, MEA
Other Regions
Reference: No agreement
Full Agreement, Single C Market
Full Agreement, Separate C Markets
Partial Agreement, Single C Market
Partial Agreement, Seperate C Markets

Consumption Road Transport





Conclusion

- One market versus two makes very little difference
- Full participation versus partial participation makes an enormous difference in energy portfolios and CC mitigation

Part 2. Renewable Energy Potential: Municipal Residue Biomass

How important is a technology or resource in addressing climate change, sustainable development, and energy security relative to other options?

Definition

Municipal Residue Biomass (MRB)

=

Biomass Proportion of Municipal Solid Waste (MSW)

=

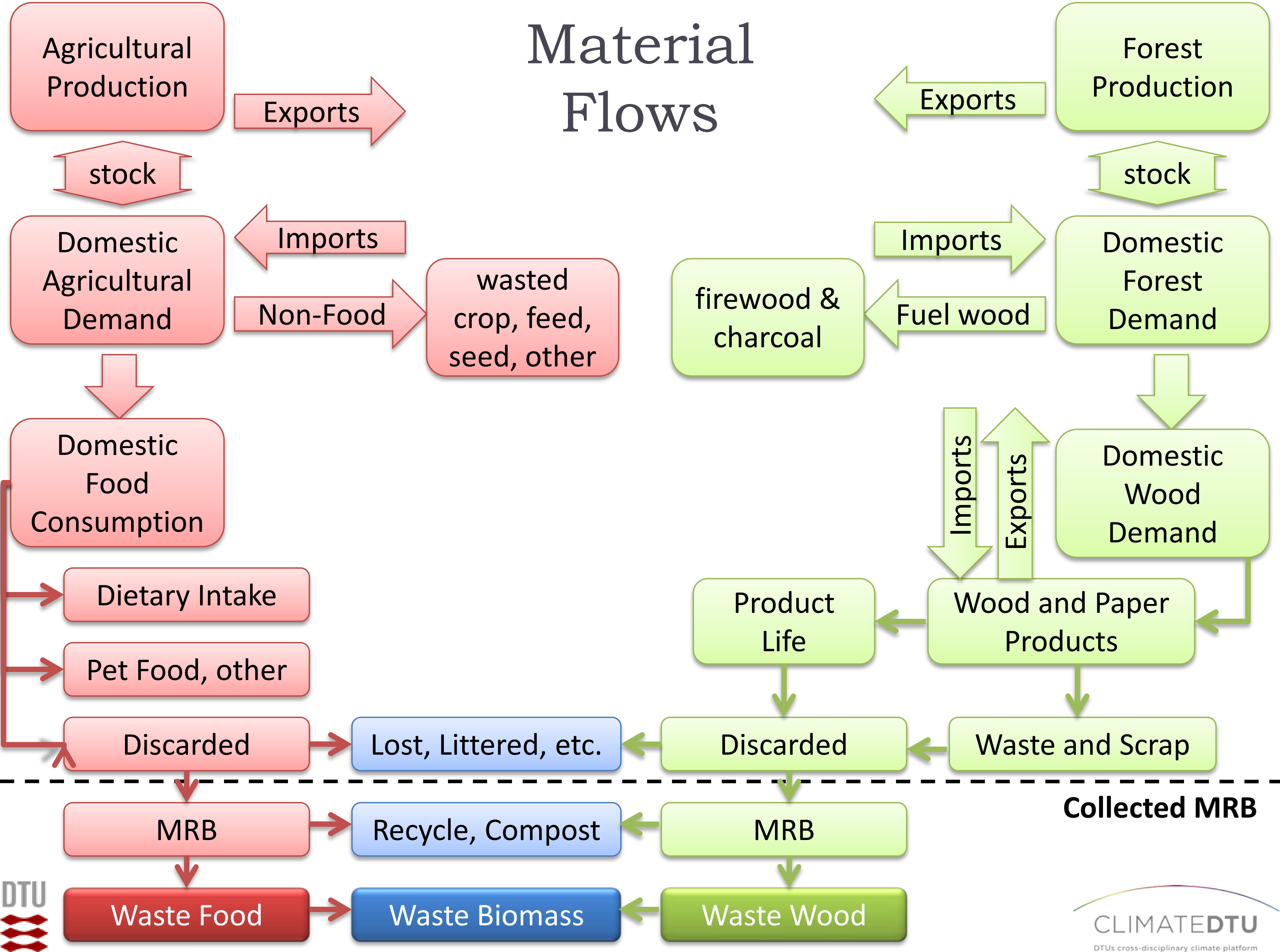
Garbage

Benefits of Energy from Municipal Residue Biomass (MRB)

MRB:

- is already collected and aggregated in urban centers where energy demands are high
- increases with population and affluence
- is a non-seasonal source of biomass (potential biofuel feedstock)
- as Waste to Energy, reduces demand for landfills in urban areas & GHG emissions

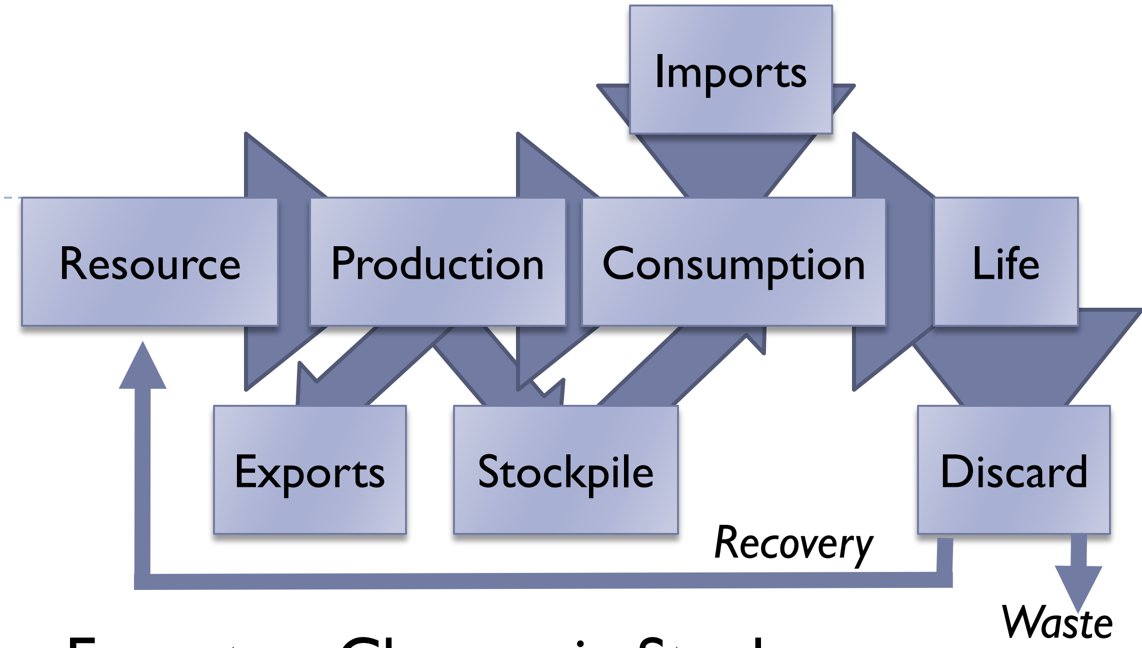
Material Flows



MRB Potential

- How much biomass waste is there (food, wood, and paper)?
- How does it vary across the world and change as economies develop?
- What effect does a carbon policy have on waste-to-energy utilization?

Method



<u>For each country/ region:</u>

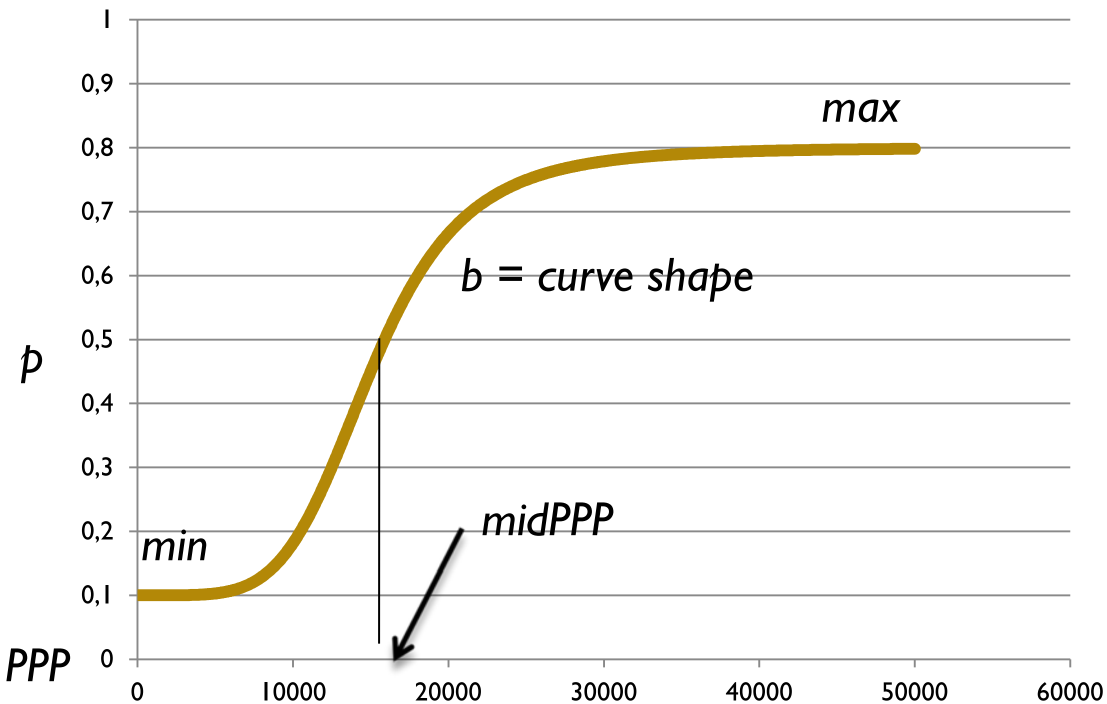
- Consumption =

  Production + Imports – Exports – Changes in Stock
- Life ~Γ(*mean lifetime* ,1)
- $p_{service}$: proportion of the population have MSW collection service
- p_{MRB}: proportion of the waste that is discarded into MRB stream (vs. littered, lost, user-recovered, user-burned)
- $p_{recover}$: proportion of MRB that is recycled, composted, or reused by the municipality

In Formula Form

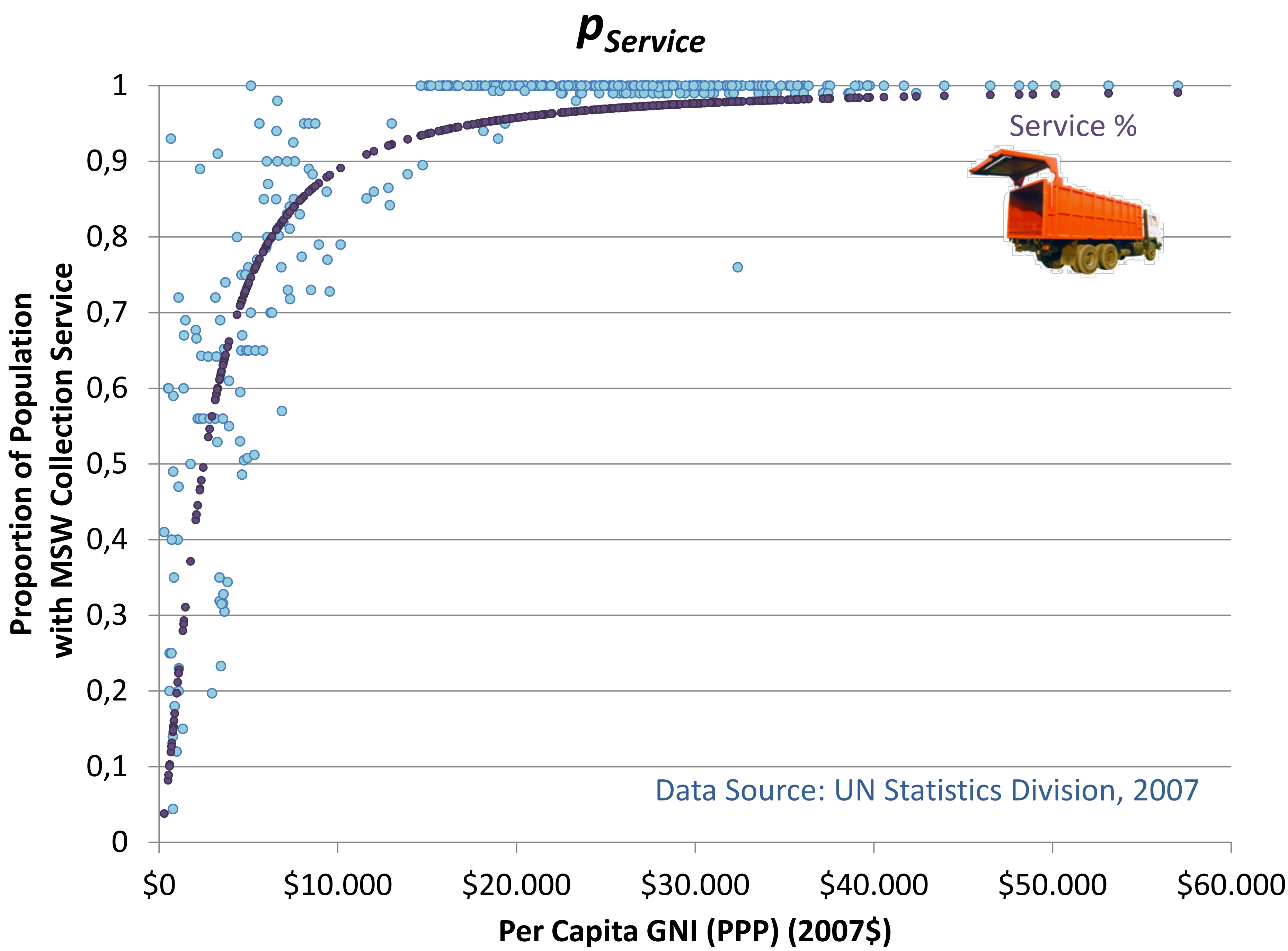
Collected Biomass Residue =

$$\text{Discarded Biomass} \times p_{service} \times p_{MRB} \times (1 - p_{recover})$$

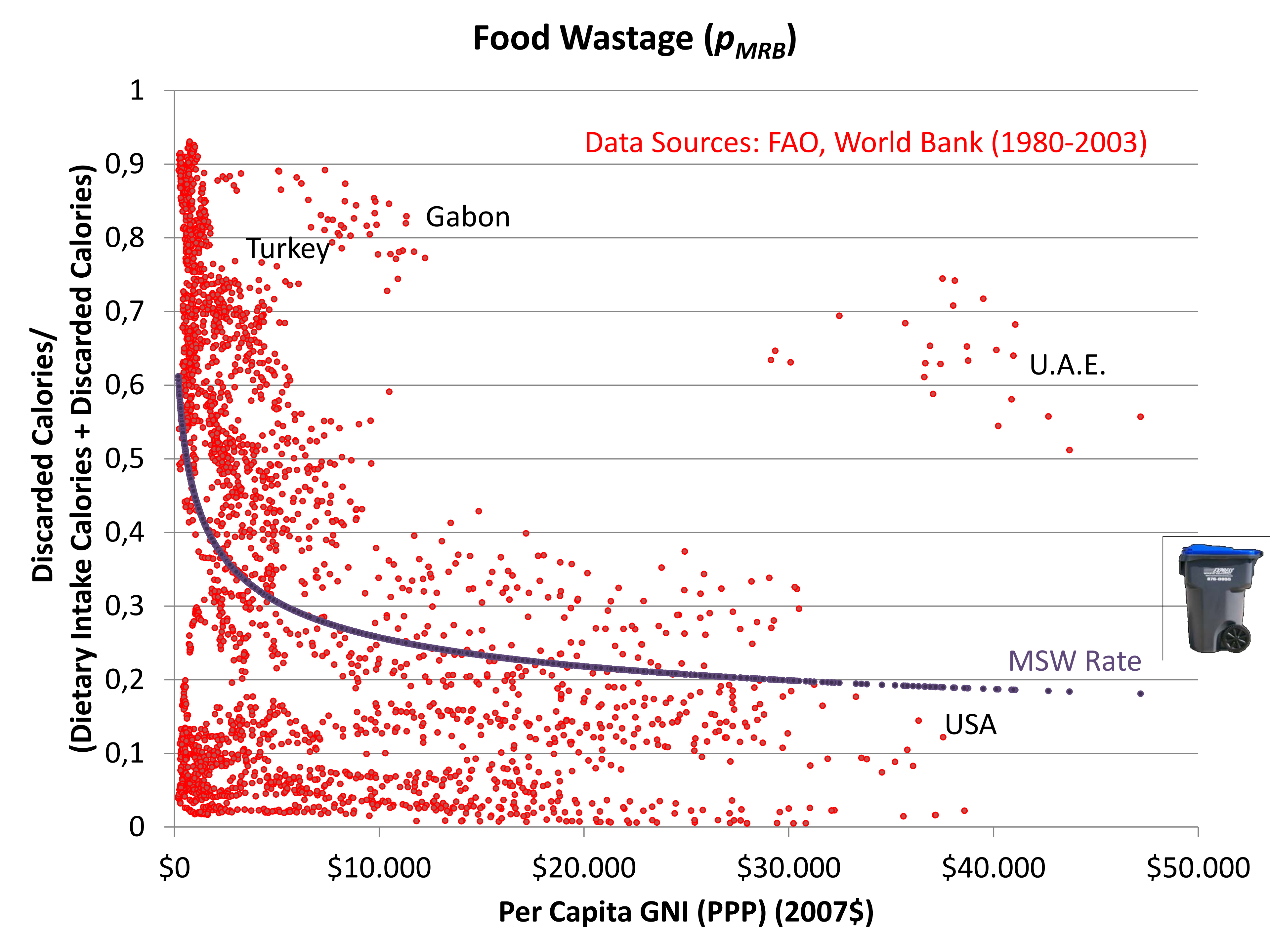


Statistical Fits: Logistic Equations

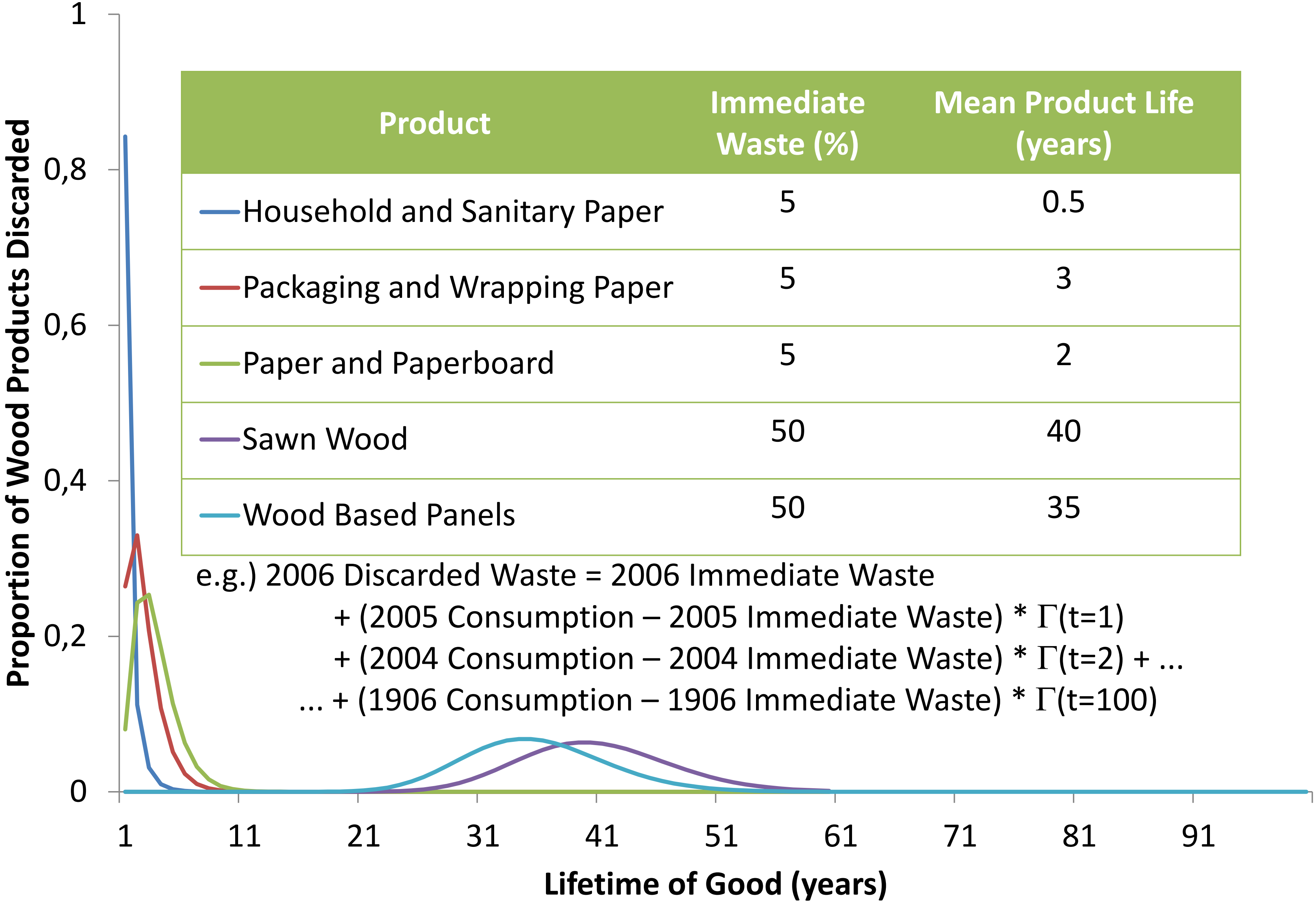
$$p = min + \frac{(max - min) \times PPP^b}{midPPP^b + PPP^b}$$



$p_{Service}$
Service %
Proportion of Population with MSW Collection Service
1
0,9
0,8
0,7
0,6
0,5
0,4
0,3
0,2
0,1
0
$0
$10.000
$20.000
$30.000
$40.000
$50.000
$60.000
Per Capita GNI (PPP) (2007$)
Data Source: UN Statistics Division, 2007

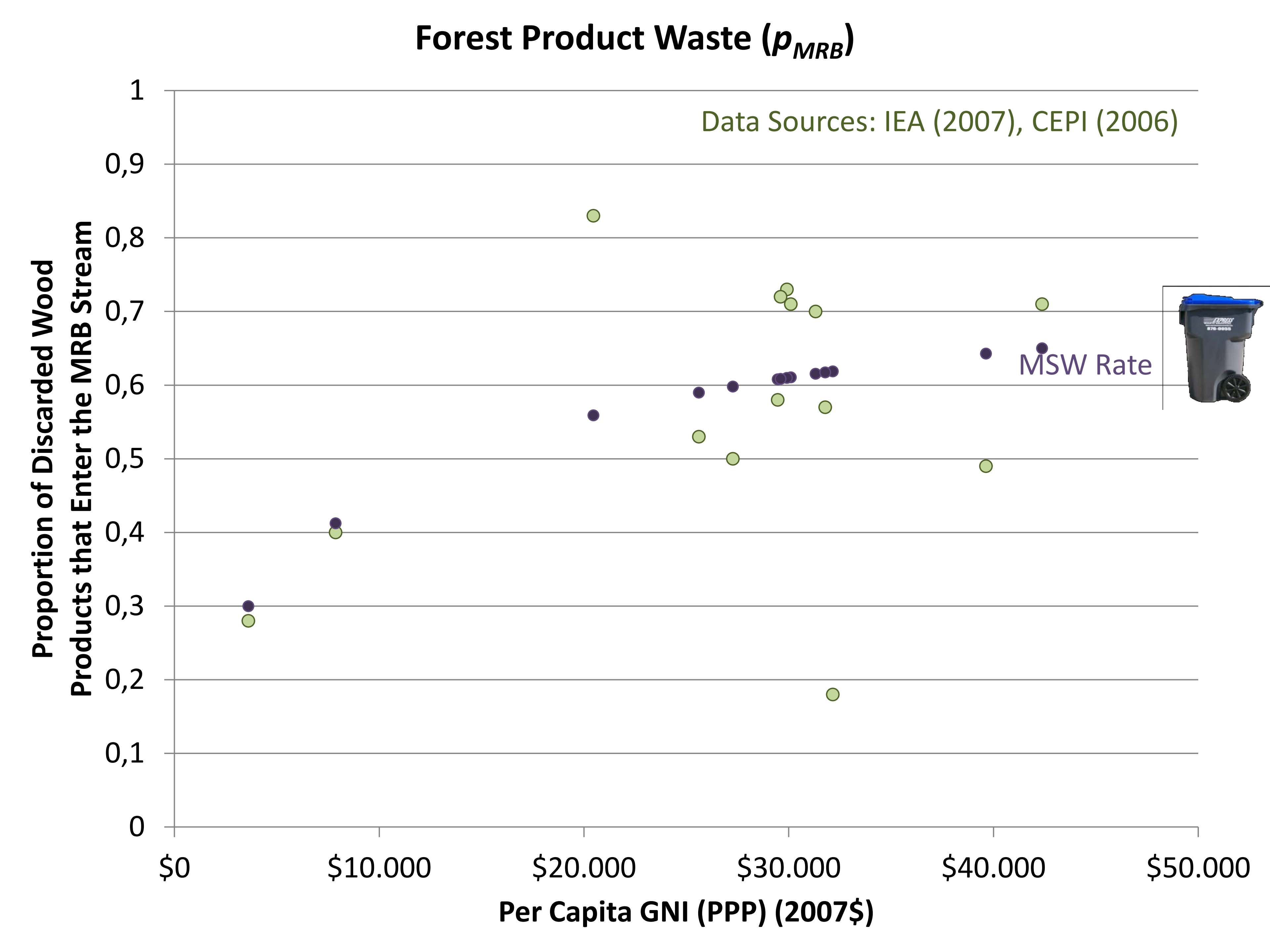

Food Wastage (p_{MRB})
Data Sources: FAO, World Bank (1980-2003)
Gabon
Turkey
U.A.E.
MSW Rate
USA
1
0,9
0,8
0,7
0,6
0,5
0,4
0,3
0,2
0,1
0
$0
$10.000
$20.000
$30.000
$40.000
$50.000
Discarded Calories/
(Dietary Intake Calories + Discarded Calories)
Per Capita GNI (PPP) (2007$)

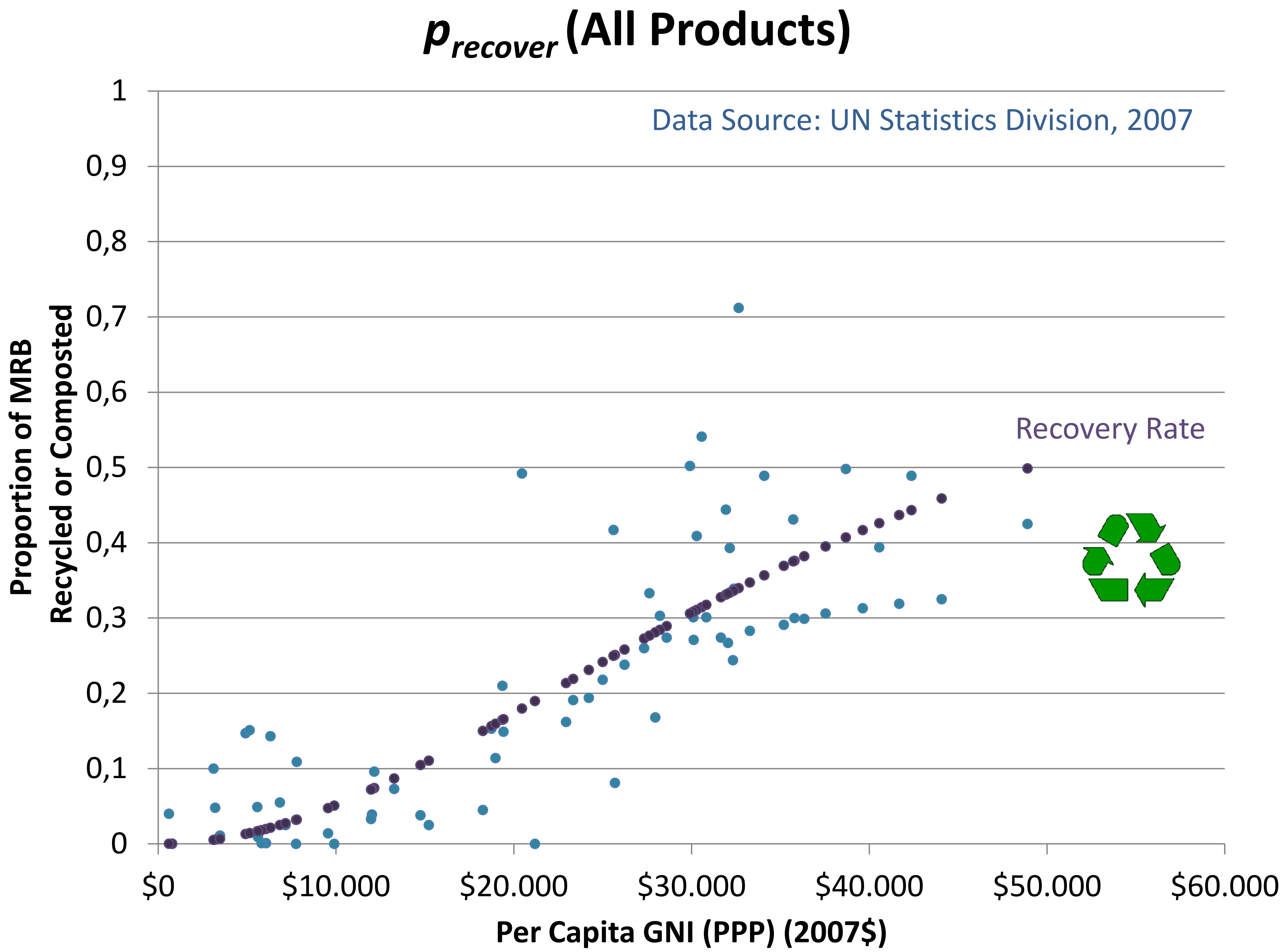
Lifetime of Wood and Paper Products (Gamma Distribution)



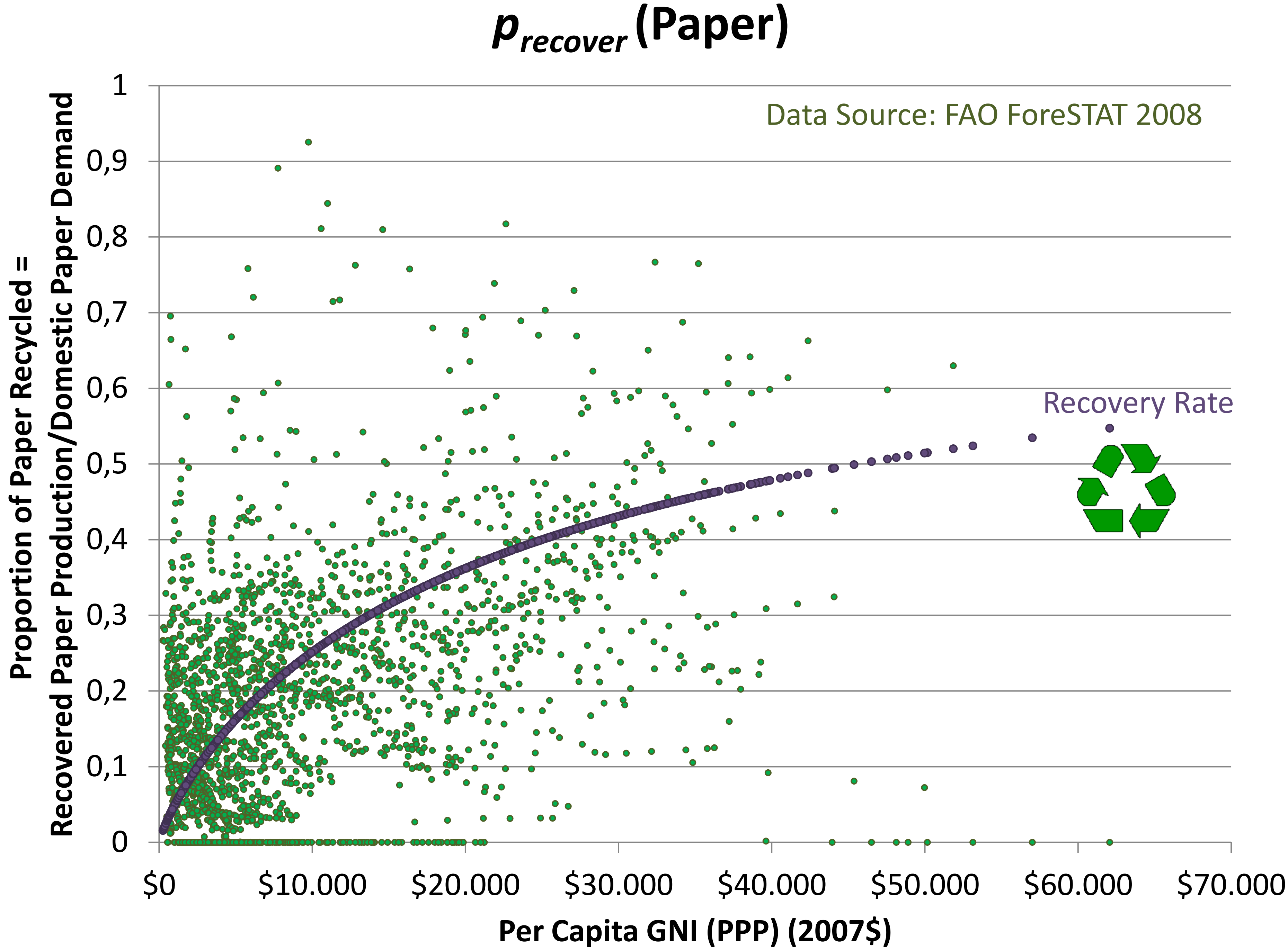
Product	Immediate Waste (%)	Mean Product Life (years)
Household and Sanitary Paper	5	0.5
Packaging and Wrapping Paper	5	3
Paper and Paperboard	5	2
Sawn Wood	50	40
Wood Based Panels	50	35

e.g.) 2006 Discarded Waste = 2006 Immediate Waste
+ (2005 Consumption – 2005 Immediate Waste) * Γ(t=1)
+ (2004 Consumption – 2004 Immediate Waste) * Γ(t=2) + ...
... + (1906 Consumption – 1906 Immediate Waste) * Γ(t=100)


Forest Product Waste (p_{MRB})
Data Sources: IEA (2007), CEPI (2006)
MSW Rate
Proportion of Discarded Wood Products that Enter the MRB Stream
Per Capita GNI (PPP) (2007$)
1
0,9
0,8
0,7
0,6
0,5
0,4
0,3
0,2
0,1
0
$0
$10.000
$20.000
$30.000
$40.000
$50.000



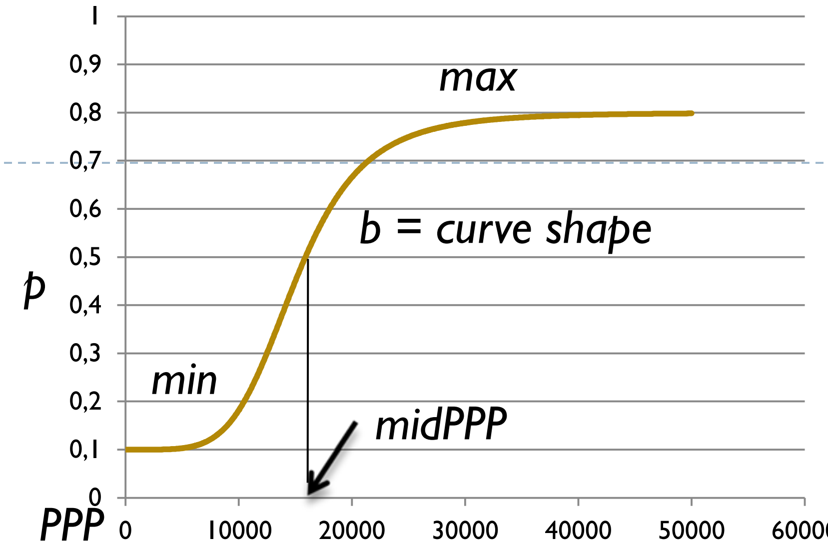
$p_{recover}$ (All Products)
Data Source: UN Statistics Division, 2007
Recovery Rate
Proportion of MRB Recycled or Composted
Per Capita GNI (PPP) (2007$)
1
0,9
0,8
0,7
0,6
0,5
0,4
0,3
0,2
0,1
0
$0
$10.000
$20.000
$30.000
$40.000
$50.000
$60.000



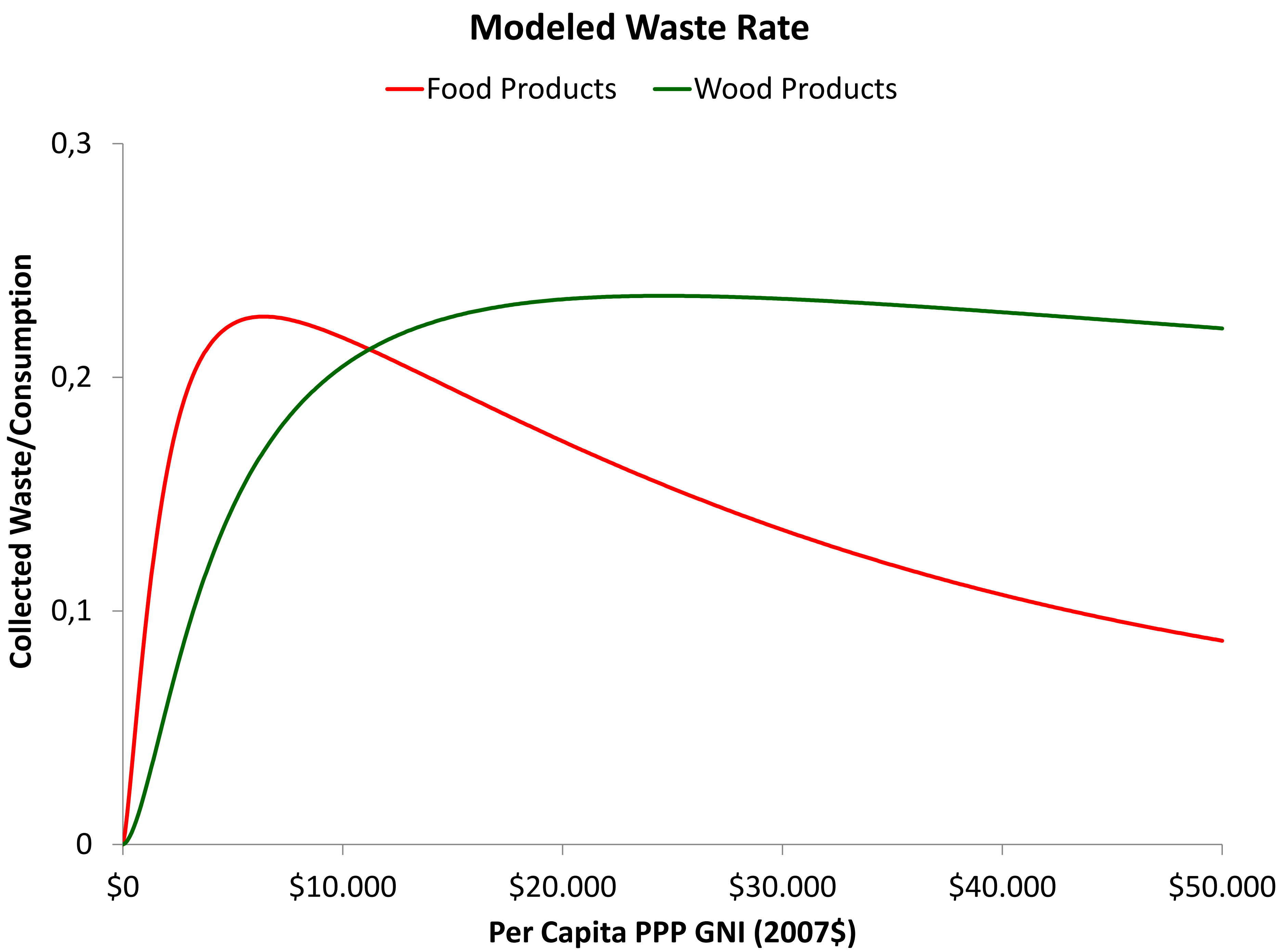
$p_{recover}$ (Paper)
Data Source: FAO ForeSTAT 2008
Recovery Rate
Proportion of Paper Recycled =
Recovered Paper Production/Domestic Paper Demand
Per Capita GNI (PPP) (2007$)
0
0,1
0,2
0,3
0,4
0,5
0,6
0,7
0,8
0,9
1
$0
$10.000
$20.000
$30.000
$40.000
$50.000
$60.000
$70.000

Fitted Parameters Summary

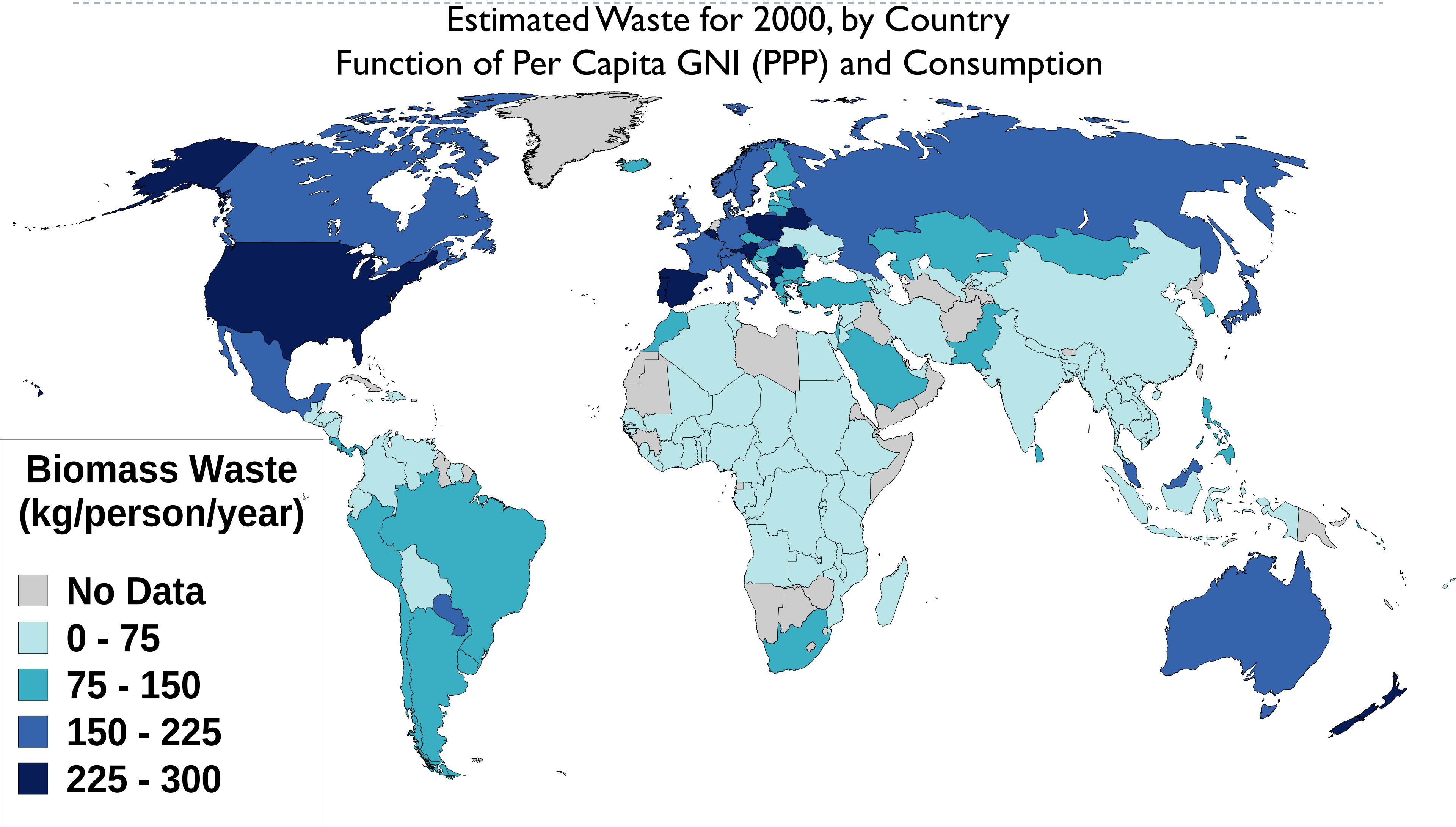
$$p = min + \frac{(max - min) \times PPP^b}{midPPP^b + PPP^b}$$



	Model parameter	$p_{service}$	p_{MRB}	$p_{recover}$
FOOD	*min*	0	0.1	0
	max	1	0.9	0.8
	midPPP	\$2,500	\$600	\$38,000
	b	1.5	-0.5	2
WOOD	*min*	0	0.1	0
	max	1	0.9	0.8
	midPPP	\$2,500	\$10,000	\$25,000
	b	1.5	0.9	0.85


Modeled Waste Rate
Food Products
Wood Products
0,3
0,2
0,1
0
Collected Waste/Consumption
$0
$10.000
$20.000
$30.000
$40.000
$50.000
Per Capita PPP GNI (2007$)

Modeled Biomass Waste



A Tonne of Waste…

- can be buried in a landfill

  decomposing into 1800 kg of CO_2-eq (GWP) CH_4 and CO_2 emissions.

  OR

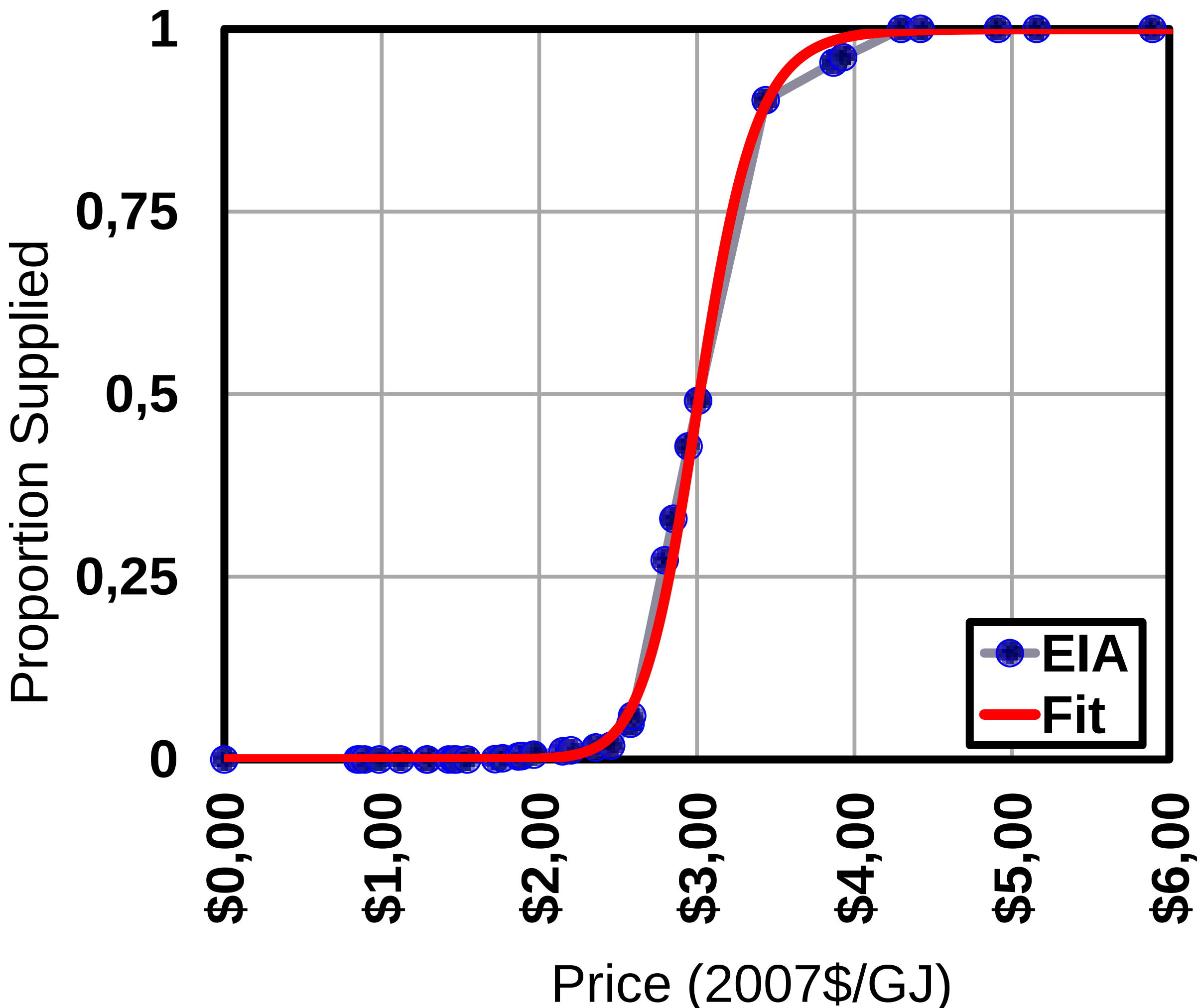
- can be converted into about

  8 GJ of energy

  resulting in only

  640 kg of CO_2 emissions

Market for Biomass Energy



$3/GJ biomass =

~$60/tonne switchgrass

~$20/bbl crude oil

~30¢/therm natural gas

~$70/tonne coal

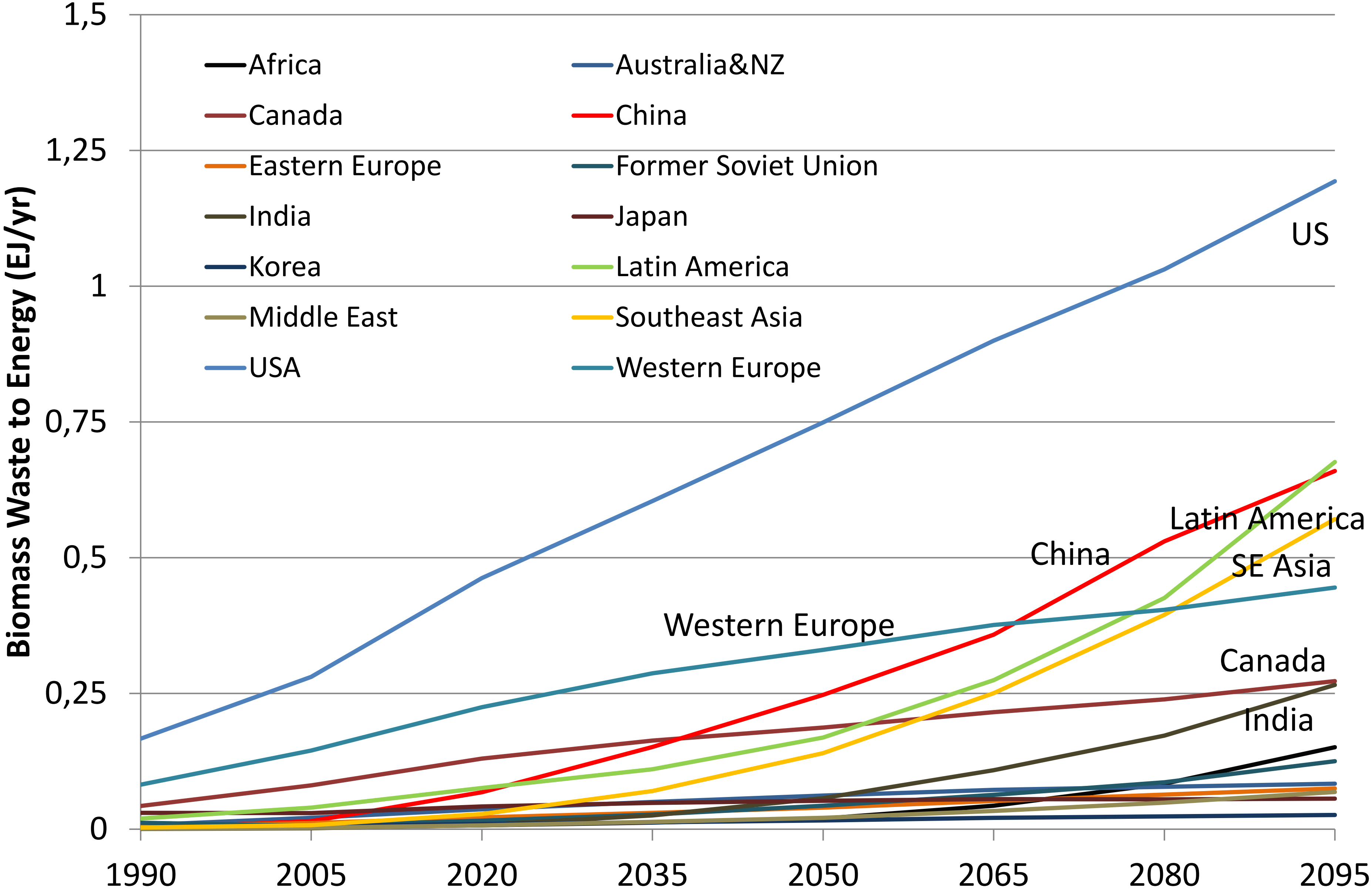
Current Prices:

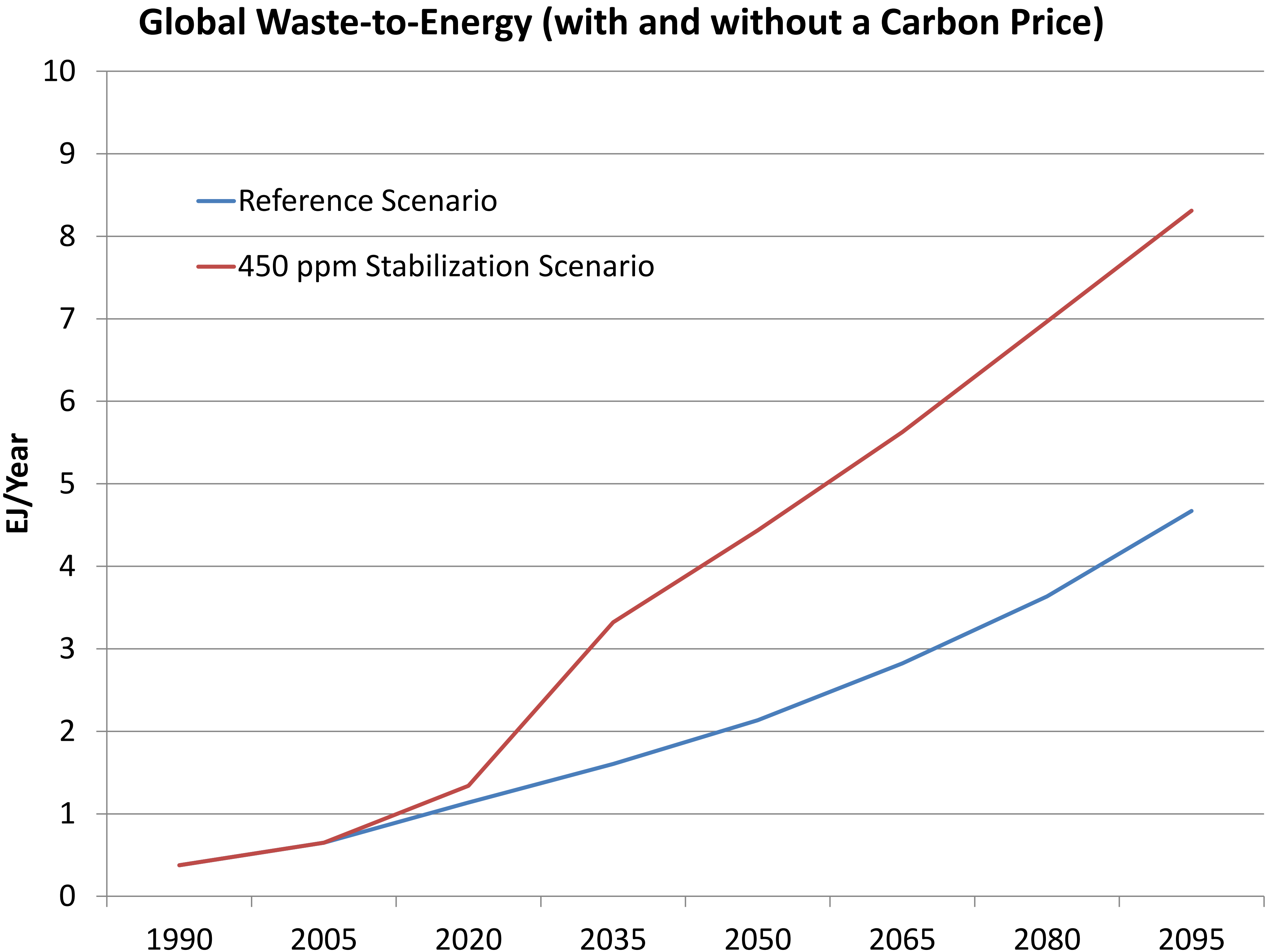
Oil: ~$100/bbl
Gas: ~30¢/therm (henry hub)
Coal: ~$100/tonne (DES ARA)

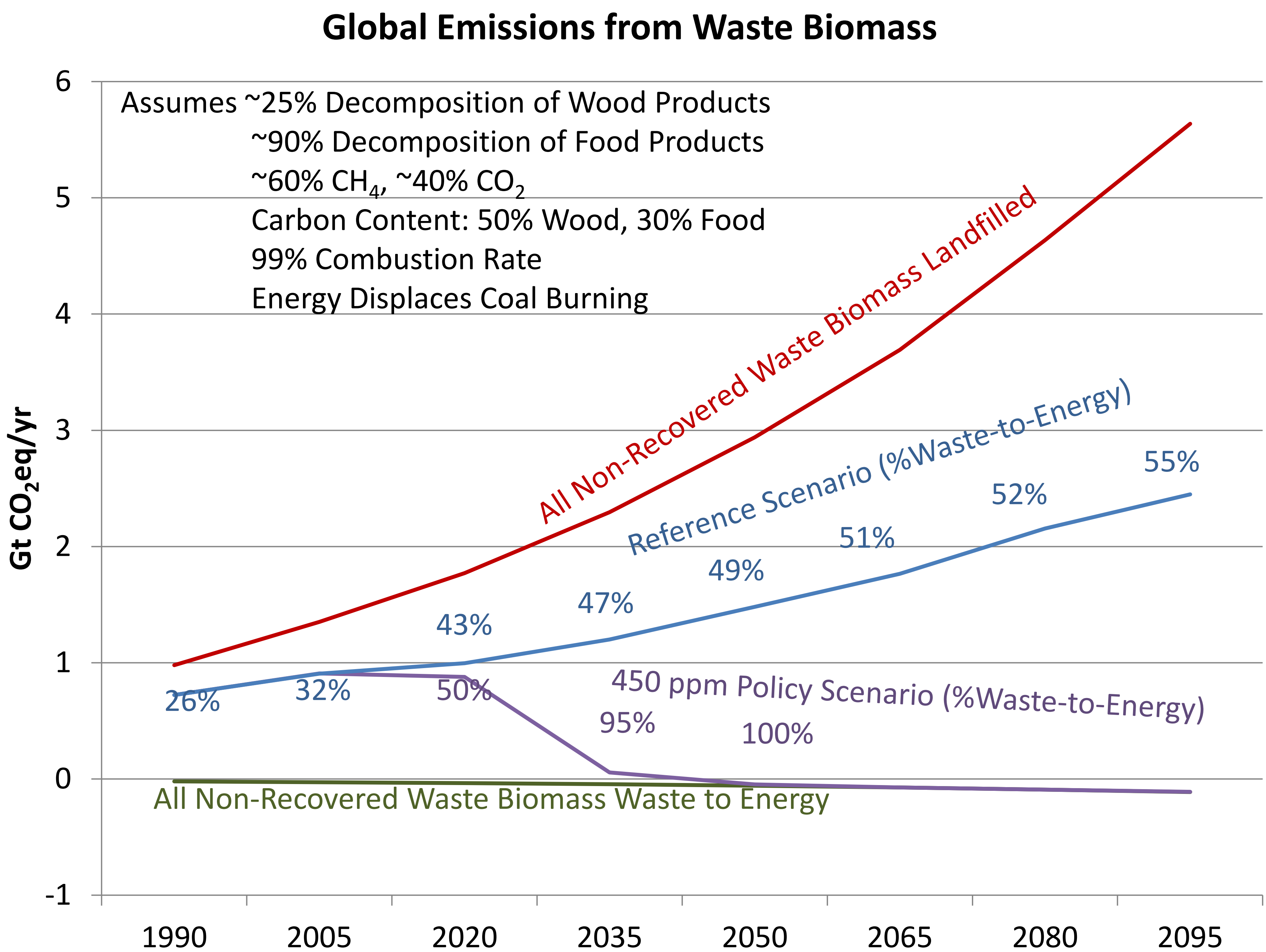
$$\textit{Proportion Supplied} = \frac{price^b}{midprice^b + price^b}$$

Data Source: EIA NEMS

Future Biomass Waste-to-Energy (Reference Scenario- No Carbon Price)




Global Waste-to-Energy (with and without a Carbon Price)
EJ/Year
0
1
2
3
4
5
6
7
8
9
10
1990
2005
2020
2035
2050
2065
2080
2095
Reference Scenario
450 ppm Stabilization Scenario


Global Emissions from Waste Biomass
Assumes ~25% Decomposition of Wood Products
~90% Decomposition of Food Products
~60% CH_4, ~40% CO_2
Carbon Content: 50% Wood, 30% Food
99% Combustion Rate
Energy Displaces Coal Burning
Gt CO_2eq/yr
6
5
4
3
2
1
0
-1
1990
2005
2020
2035
2050
2065
2080
2095
All Non-Recovered Waste Biomass Landfilled
Reference Scenario (%Waste-to-Energy)
26%
32%
43%
47%
49%
51%
52%
55%
450 ppm Policy Scenario (%Waste-to-Energy)
50%
95%
100%
All Non-Recovered Waste Biomass Waste to Energy

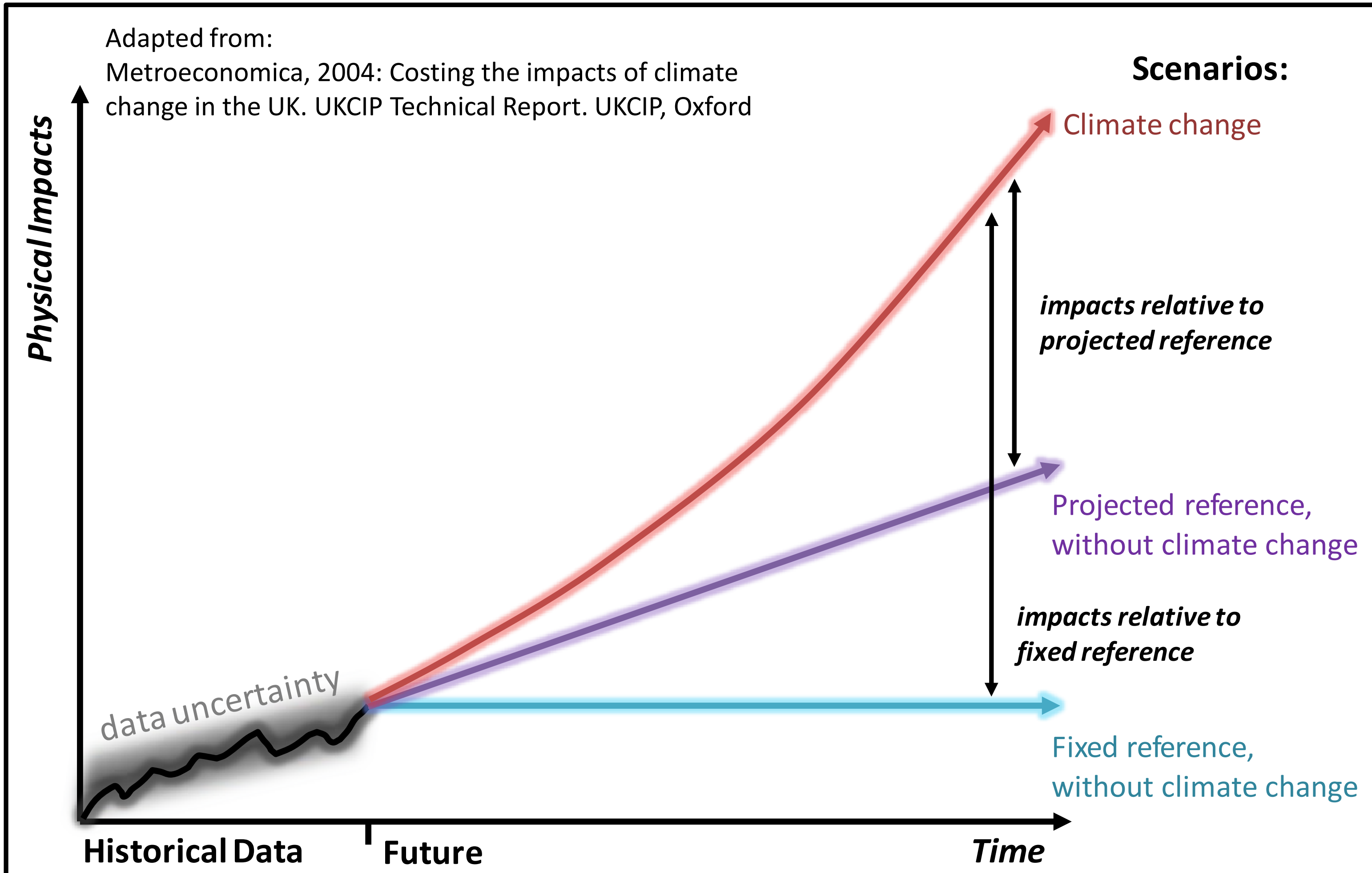
Summary & Conclusions

- MSW collection service develops relatively quickly as per capita wealth increases
- Recycling comes later; paper recycling before food composting
- Per capita collected waste biomass first increases *(increasing consumption, more access to service)*, then decreases *(more technology to reduce and recover waste)* as wealth increases
- A carbon policy incentivizes waste-to-energy as an early and inexpensive mitigation strategy

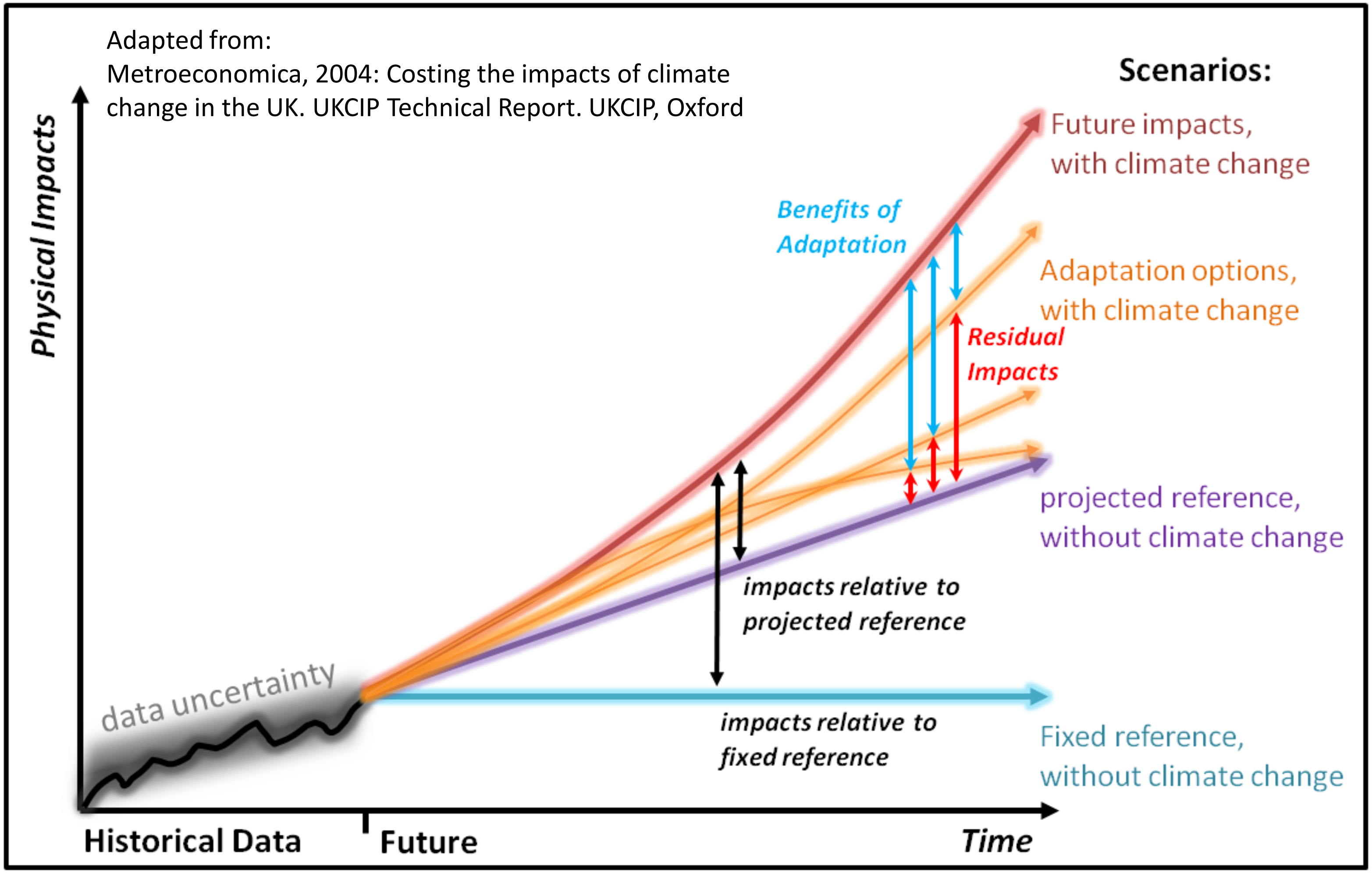
Part 3. Climate Change Impacts, Adaptation, and Decision Making

What are the extent of anticipated climate change impacts and the potential effectiveness of adaptation measures?

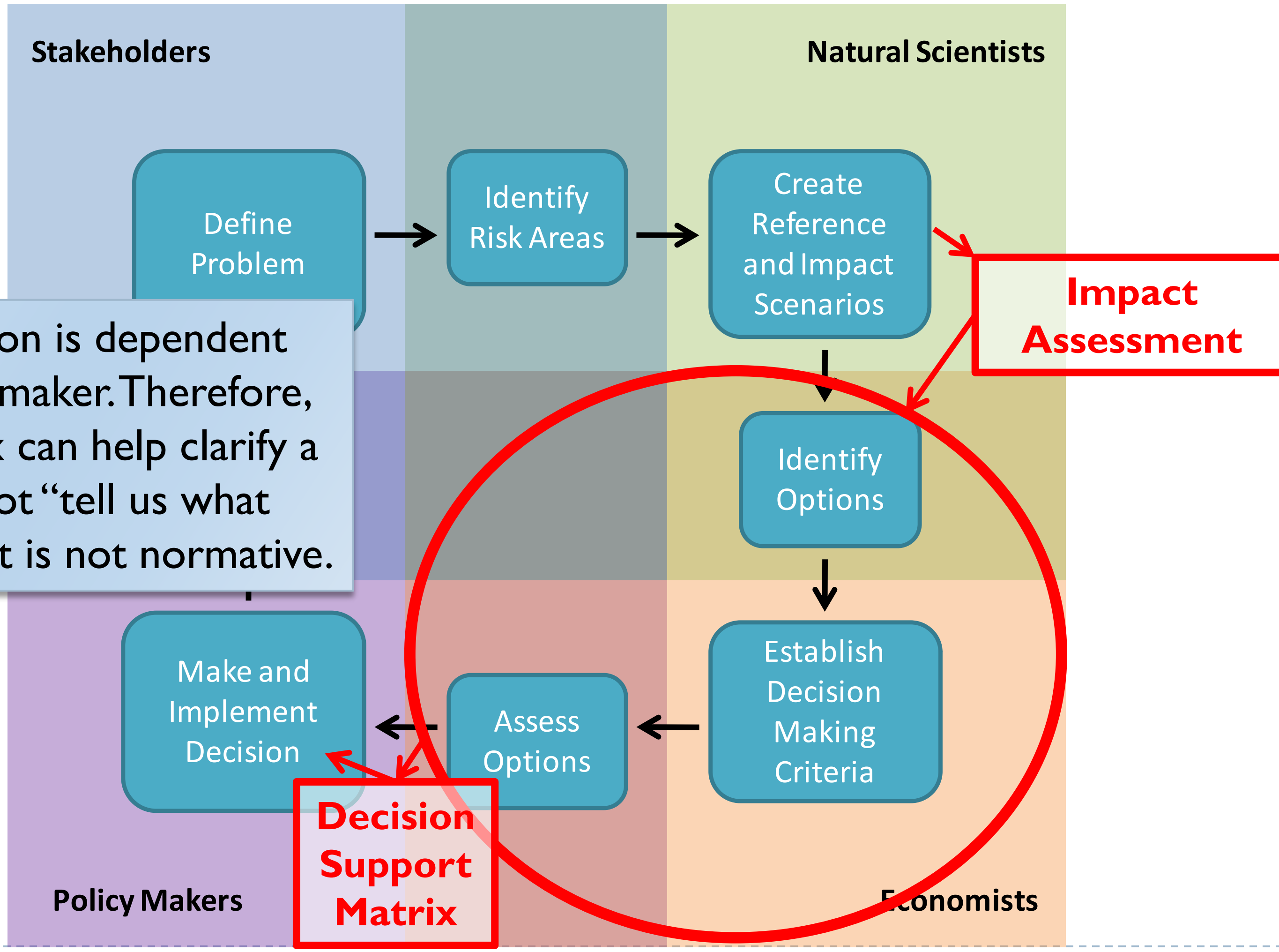
Impacts, Adaptation, and Decision Making



Impacts, Adaptation, and Decision Making

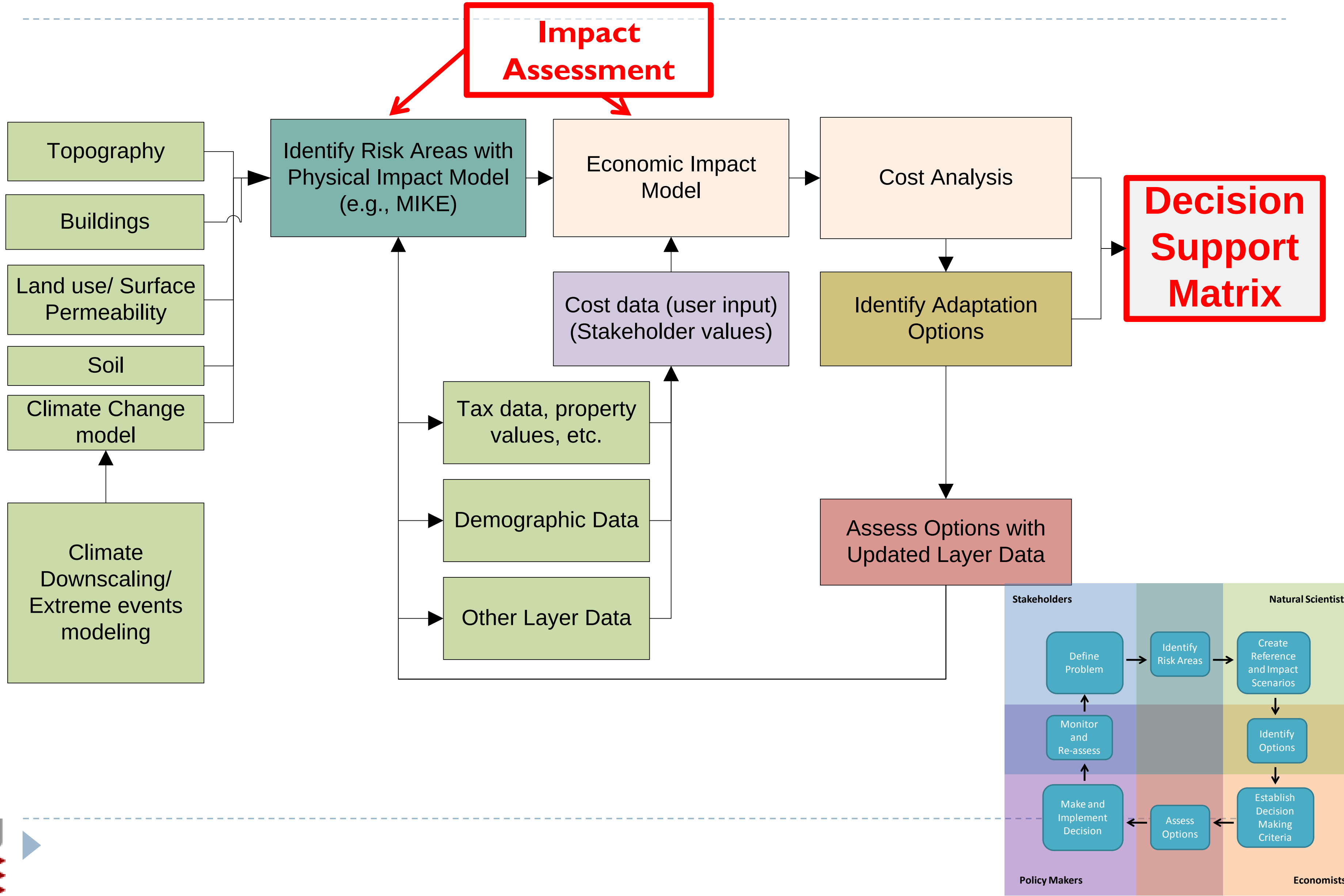


Adaptation Strategies and Decision Making: Actors and Process



The value function is dependent on the decision maker. Therefore, while the matrix can help clarify a decision, it cannot "tell us what we should do." It is not normative.

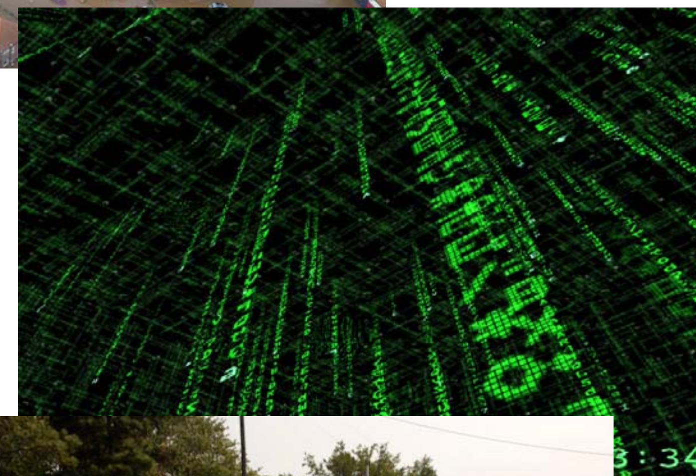
Adaptation Decision Analysis



Decision Making

- Impact Assessment

- Decision Support Matrix



- *Adaptation Decisions are Based Upon:*
  - damage assessments
  - weighting of impacts
  - attitudes toward risk
  - parallel/competing goals with existing and concurrent policies
  - predefined non-negotiable constraints

Whose decision is it, anyway?

Should adaptation be the responsibility of the state, the municipality, the community, or the individual?

Impact Assessment

- ***Goal***:
  - identify impacted areas
  - highlight key uncertainties
  - inform decision makers on which adaptation options make sense

Identifying Risk Areas: How are These Defined?

- Climate change can increase the probability of a number of different impacts

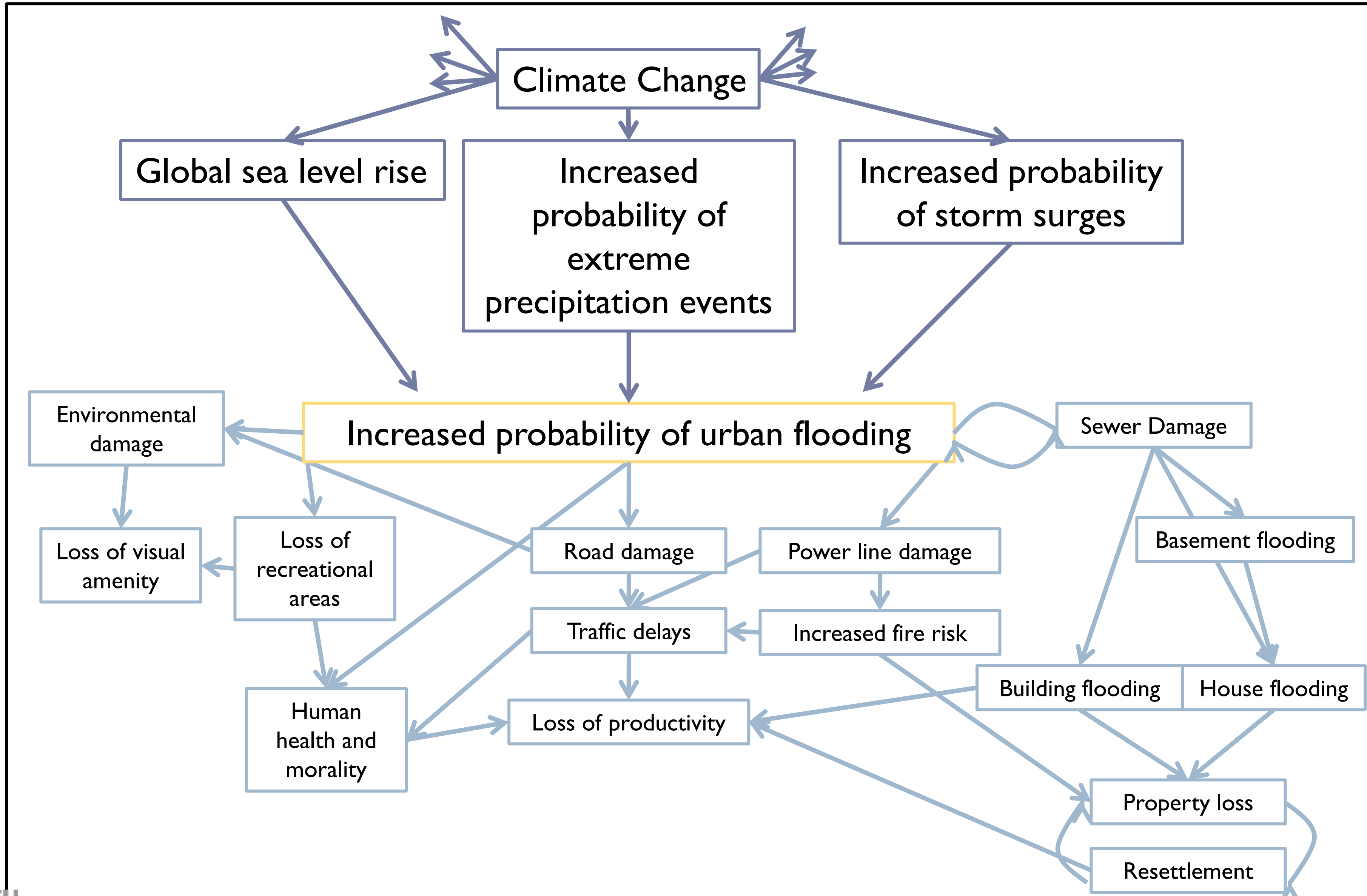
- How do we select the impacts of interest?
- How do we assess these?

Identifying Risks and Impacts

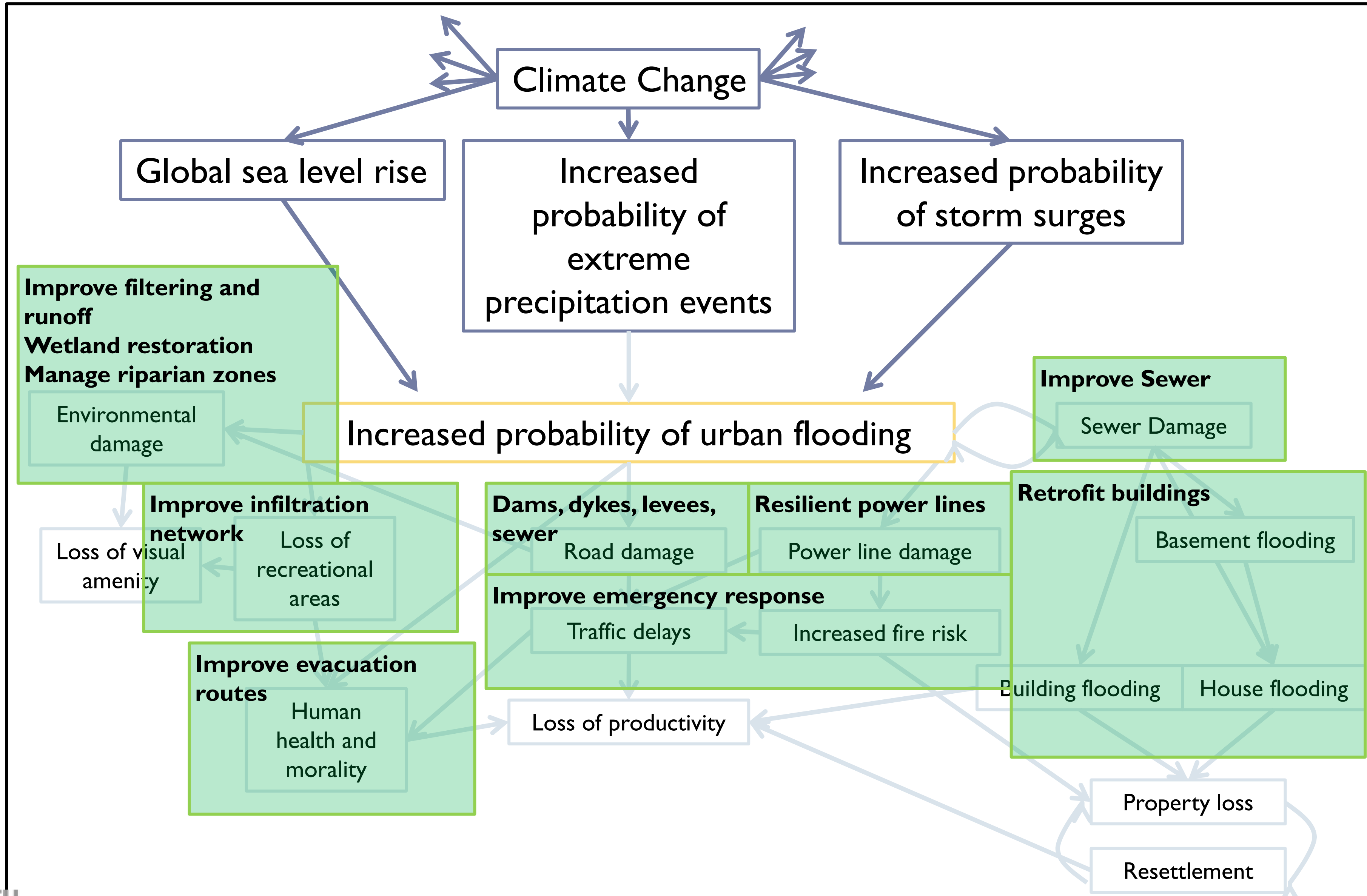
Impact	Physical measure	Direct Cost	Additional Consequences
Flooding of basement in houses	Number of houses and area	Repair	Loss of irreplaceable objects
Erosion of road	Distance of road	Repair	Traffic congestion and delay
Illness from water pollution	Number of person days with sickness	Lost salary, Lost productivity	General loss of wellbeing loss of life
Flooding of local lake	Impacts on life in the lake water level	Clean up, restoration	Esthetic value, loss of recreational area illness
Flooding of unique historical building	Physical character of the building	Repair and replacement	Esthetic values
Traffic delay	Time	Lost salary, Lost productivity	Worker morale, lost time for leisure
Loss of recreational areas	Area inundated	Reparation, clean up, replacement	Lost leisure, visual amenity

etc.

Causal Chain of Impacts



Mapping Adaptation Options



Impact Assessment within the Decision Making Framework

Decision Support Matrix: A systematic way of comparing available choices and options (*rows*) on the basis of a set of criteria (*columns*) associated with each hypothetical outcome

from the climate model

Adaptation option	Cost of imple-mentating option *i*	Impact a, given option *i*	Preference factor for impact a	Impact b, given option *i*	Preference factor for impact b	…	Proba-bility of extreme event	Damage
O_R	0	$a_R = a\|O_R$	w_a	$b_R = b\|O_R$	w_b	…	$p(x_R)$	$V(O_R) = p(x_R)^*(w_a^*a_R + w_b^* b_R+…)$
O_0	0	$a_0 = a\|O_0$	w_a	$b_0 = b\|O_0$	w_b	…	$p(x)$	$V(O_0) = p(x)^*(w_a^*a_0 + w_b^* b_0+…) - V(O_R)$
O_1	$C(O_1)$	$a_1 = a\|O_1$	w_a	$b_1 = b\|O_1$	w_b	…	$p(x)$	$C(O_1)+p(x)^*(w_a^*a_1 + w_b^* b_1+…)- V(O_0)$
O_2	$C(O_2)$	$a_2 = a\|O_2$	w_a	$b_2 = b\|O_2$	w_b	…	$p(x)$	$C(O_2)+p(x)^*(w_a^*a_2 + w_b^* b_2+…)- V(O_0)$
O_3	$C(O_3)$	$a_3 = a\|O_3$	w_a	$b_3 = b\|O_3$	w_b	…	$p(x)$	$C(O_3)+p(x)^*(w_a^*a_3 + w_b^* b_3+…)- V(O_0)$
:	:	:	:	:	:	.:.	:	:
O_n	$C(O_n)$	$a_n = a\|O_n$	w_a	$b_n = b\|O_n$	w_b	…	$p(x)$	$C(O_n)+p(x)^*(w_a^*a_n + w_n^* b_n+…)- V(O_0)$

←reference scenario, no climate change

←climate change scenario

damage from climate change→

←adaptation options, given climate change scenario

Which Adaptation Options?

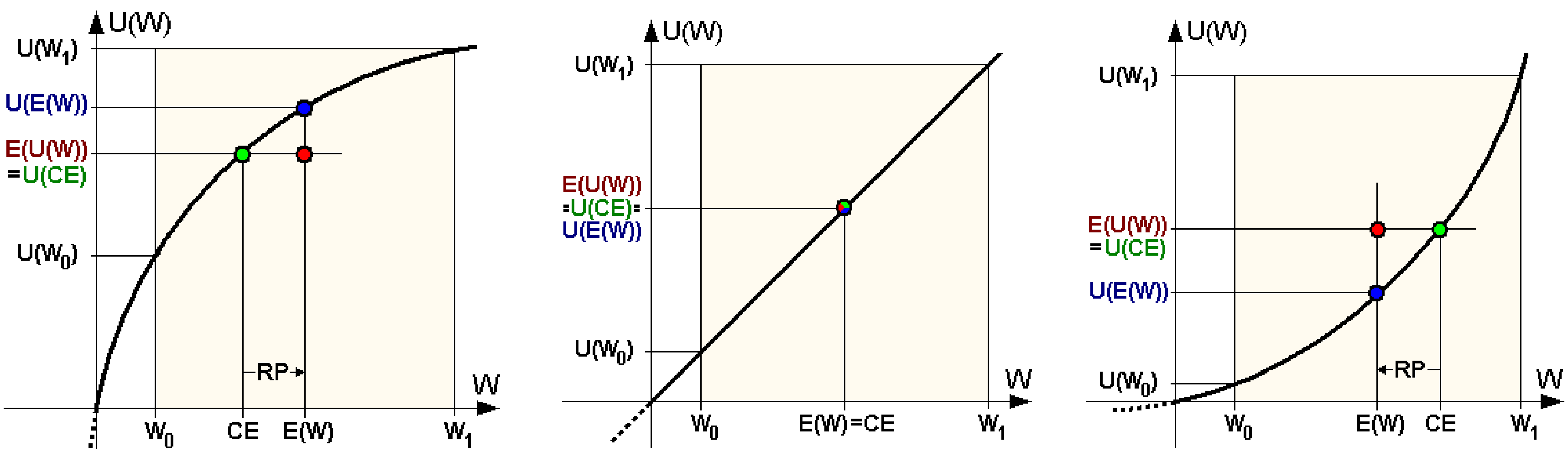
- How do the various adaptation options relate to the different damage categories?
  - e.g., expanding sewage pipes may protect more than just buildings
  - e.g., a focus on protecting a church may at the same time be a solution that will protect the adjacent buildings
- Each adaptation option is analyzed in the decision matrix.

Adaptation option	Cost of imple-mentating option *i*	Impact a, given option *i*	Preference factor for impact a	Impact b, given option *i*	Preference factor for impact b	...	Proba-bility of extreme event	Damage
O_1	$C(O_1)$	$a_1 = a \mid O_1$	w_a	$b_1 = b \mid O_1$	w_b	...	$p(x)$	$C(O_1)+p(x)^* (w_a{}^*a_1 + w_b{}^* b_1+...)- V(O_0)$
O_2	$C(O_2)$	$a_2 = a \mid O_2$	w_a	$b_2 = b \mid O_2$	w_b	...	$p(x)$	$C(O_2)+p(x)^* (w_a{}^*a_2 + w_b{}^* b_2+...)- V(O_0)$
:	:	:	:	:	:	.:.	:	:
O_n	$C(O_n)$	$a_n = a \mid O_n$	w_a	$b_n = b \mid O_n$	w_b	...	$p(x)$	$C(O_n)+p(x)^* (w_a{}^*a_n + w_n{}^* b_n+...)- V(O_0)$

Risk Aversion Factor

- Index value that reflects a risk aversion factor

- Different factors are applied to different damage elements or applied in general to the whole function.



Risk Averse Risk Neutral Risk Affine

Establishing Decision Making Criteria

- Different sets of values and assumptions about the future will result in different "optimal" decisions. In other words, there is *no* optimal decision.

- Different decisions makers will come to different decisions based upon attitudes toward risk, weighing of impacts, predefined non-negotiable constraints, and parallel/competing goals with existing and concurrent policies

Decision Support Matrix

- ***Goal:***
  - clarify the decision making process
  - identify critical assumptions
  - determine how different a priori values can influence the decision outcome

Building a Decision Support Matrix

Consider a simple case, with one impact, and one adaptation option with 3 different levels of deployment. E.g., cost of building damage due to flooding versus building a sea wall at different heights.

	Cost of implementation	Cost of climate event, given adaptation choice	p(extreme event)	Expected Cost
Nothing	0	500	.16	0+500*.16= 80
adaptation level 1	10	50	.16	10+50*.16= 18
adaptation level 2	20	20	.16	20+20*.16=23.2
adaptation level 3	100	10	.16	100+10*.16=101.6

Decision Maker: Can we provide more information on risk? How extreme is extreme?

Building a Decision Support Matrix

Now we add a more detailed description of risk, with a 10-year event, 20-year event and 100-year event.
In reality, this would be a continuous probability distribution, and we could integrate to find the expected cost.

	Cost of implementation	Cost of 10 year climate event, given adaptation choice	p(10 yr event)	Cost of 20 year climate event, given adaptation choice	p(20 yr event)	Cost of 100 year climate event, given adaptation choice	p(100 yr event)	Expected Cost
Nothing	0	500	.1	1000	.05	50000	.01	600
adaptation level 1	10	50	.1	500	.05	10000	.01	140
adaptation level 2	20	20	.1	200	.05	5000	.01	82
adaptation level 3	100	10	.1	100	.05	1000	.01	116

Decision Maker: What if I want to consider two different adaptation options?

Building a Decision Support Matrix

Now we add two different options, at 3 discrete levels, and all the permutations.
In reality, these would be a joint distribution.

	Cost of implementation	Cost of 10 year climate event, given adaptation choice	p(10 yr event)	Cost of 20 year climate event, given adaptation choice	p(20 yr event)	Cost of 100 year climate event, given adaptation choice	p(100 yr event)	Expected Cost
Nothing	0	500	0.1	1000	0.05	50000	0.01	600
Sea wall level 1	10	50	0.1	500	0.05	10000	0.01	140
Sea wall level 2	20	20	0.1	200	0.05	5000	0.01	82
Sea wall level 3	100	10	0.1	100	0.05	1000	0.01	116
Park level 1	1	400	0.1	900	0.05	40000	0.01	486
Park level 2	5	300	0.1	800	0.05	9000	0.01	165
Park level 3	10	200	0.1	700	0.05	4000	0.01	105
SW 1, park 1	11	40	0.1	400	0.05	4000	0.01	75
SW2, park 1	21	15	0.1	150	0.05	1500	0.01	45
SW 3, park 1	101	8	0.1	80	0.05	800	0.01	113.8
SW 1, park 2	5	30	0.1	300	0.05	3000	0.01	53
SW 2, park 2	25	12	0.1	120	0.05	1200	0.01	44.2
SW 3, park 2	105	5	0.1	50	0.05	500	0.01	113
SW 1, park 3	20	10	0.1	100	0.05	1000	0.01	36
SW 2, park 3	30	5	0.1	50	0.05	500	0.01	38
SW 3, park 3	110	2	0.1	20	0.05	200	0.01	113.2

Decision Maker: What if I want to consider more than one type of impact, each with different units?

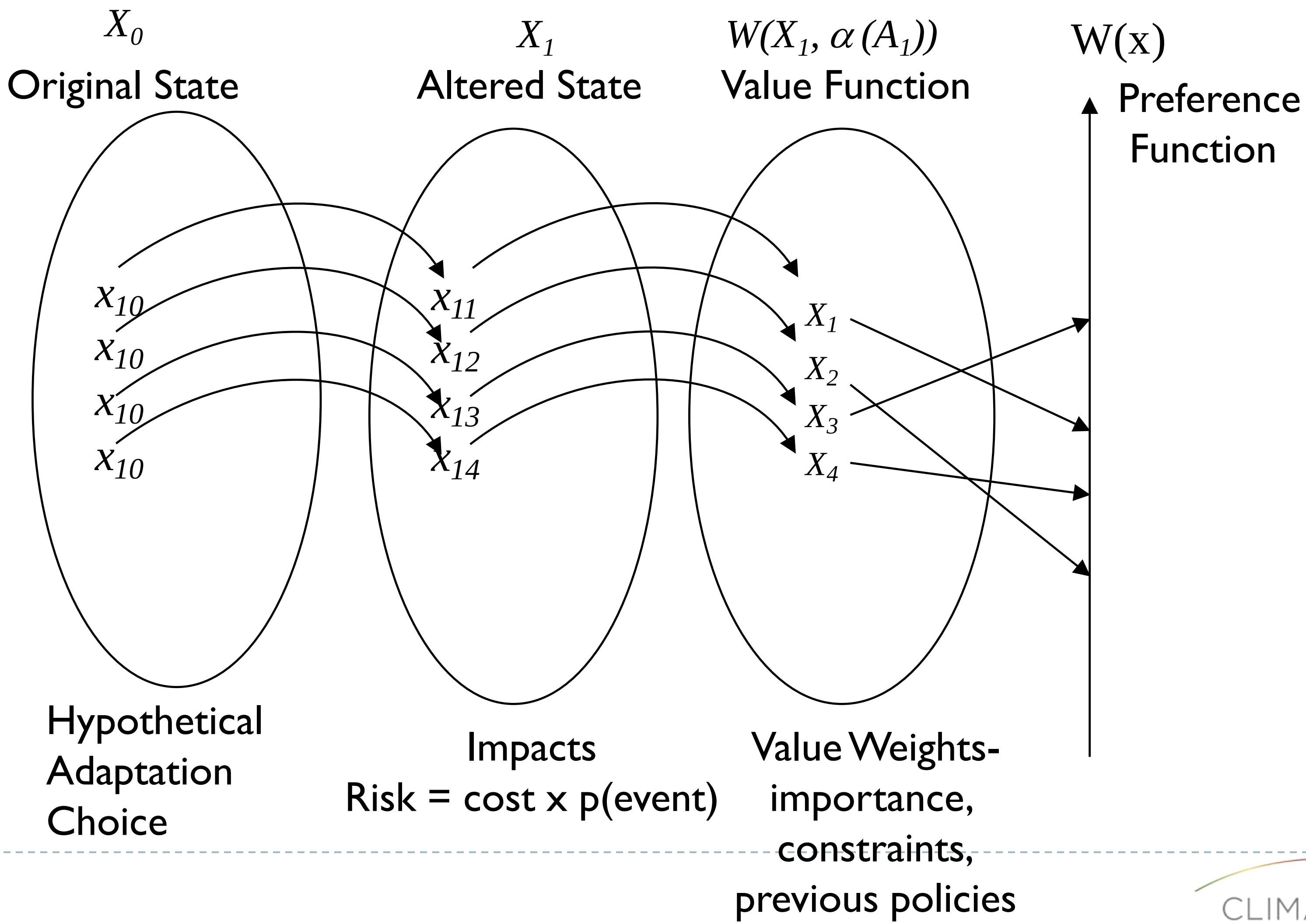
Building a Decision Support Matrix

Now we add two impacts, with different cost units (e.g., one monetary, one non-monetary)

	Cost of implementation	Cost of 10 year climate event, given adaptation choice		p(10 yr event)	Cost of 20 year climate event, given adaptation choice		p(20 yr event)	Cost of 100 year climate event, given adaptation choice		p(100 yr event)	Expected Cost	
Nothing	0	500	30	0.1	1000	50	0.05	50000	100	0.01	600	6.5
Sea wall level 1	10	50	1	0.1	500	5	0.05	10000	15	0.01	140	10.5
Sea wall level 2	20	20	0	0.1	200	2	0.05	5000	10	0.01	82	20.2
Sea wall level 3	100	10	0	0.1	100	0	0.05	1000	5	0.01	116	100.1
Park level 1	1	400	1	0.1	900	5	0.05	40000	20	0.01	486	1.55
Park level 2	5	300	0	0.1	800	2	0.05	9000	10	0.01	165	5.2
Park level 3	10	200	0	0.1	700	0	0.05	4000	9	0.01	105	10.09
SW 1, park 1	11	40	0	0.1	400	3	0.05	4000	10	0.01	75	11.25
SW2, park 1	21	15	0	0.1	150	1	0.05	1500	6	0.01	45	21.11
SW 3, park 1	101	8	0	0.1	80	1	0.05	800	4	0.01	113.8	101.1
SW 1, park 2	5	30	0	0.1	300	1	0.05	3000	8	0.01	53	5.13
SW 2, park 2	25	12	0	0.1	120	0	0.05	1200	5	0.01	44.2	25.05
SW 3, park 2	105	5	0	0.1	50	0	0.05	500	3	0.01	113	105
SW 1, park 3	20	10	0	0.1	100	1	0.05	1000	6	0.01	36	20.11
SW 2, park 3	30	5	0	0.1	50	0	0.05	500	2	0.01	38	30.02
SW 3, park 3	110	2	0	0.1	20	0	0.05	200	1	0.01	113.2	110

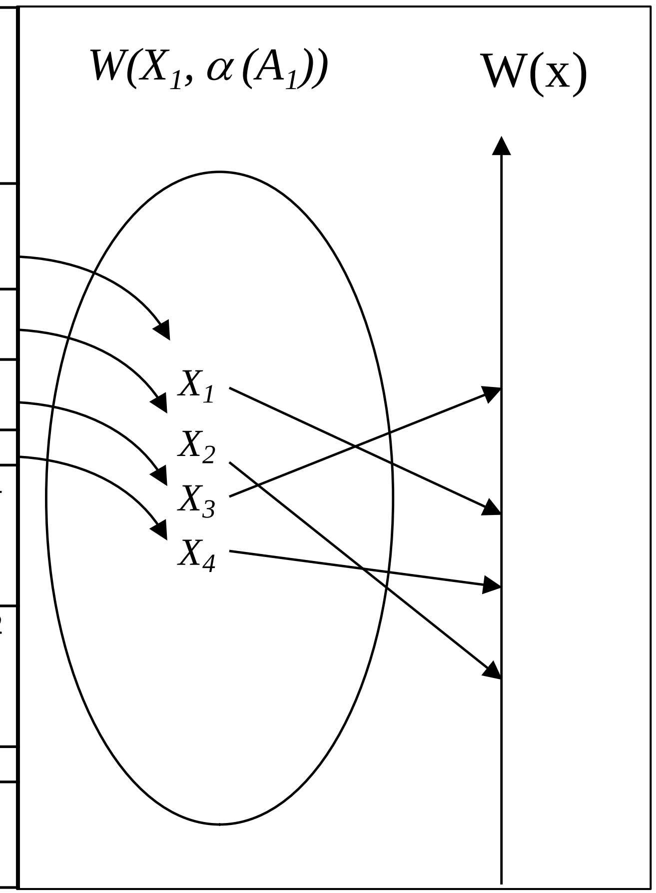
Decision Maker: How do I decide between the two expected costs? What level of risk is acceptable across all variables?

Building a Decision Support Matrix



Hypothetical Decision Support Matrix

	Reference Outcome 1 (current state, no CC)	Reference Outcome 2 (current trend, no CC)	Impact 1 Outcome (with CC)	Impact 2 Outcome (with CC)	…	Impact *i* Outcome (with CC)
no adaptation	baseline reference scenario	projected reference scenario	scenario 0 outcome 1	Scenario 0 outcome 2	…	scenario 0 outcome *i*
Adaptation option 1	X	X	Scenario 1 outcome 1	Scenario 1 outcome 2	…	Scenario 1 outcome *i*
Adaptation option 2	X	X	Scenario 2 outcome 1	Scenario 2 outcome 2	…	Scenario 2 outcome *i*
:	:	:	:	:	:	:
multiple adaptation options (1,2, …)	X	X	Scenario p1 outcome 1	Scenario p1 outcome 2	…	Scenario p1 outcome *i*
multiple adaptation options (1,2, …)	X	X	Scenario p2 outcome 1	Scenario p2 outcome 2	…	Scenario p2 outcome *i*
:	:	:	:	:	:	:
all adaptation options	X	X	Scenario F outcome 1	Scenario F outcome 2	…	Scenario F outcome *i*



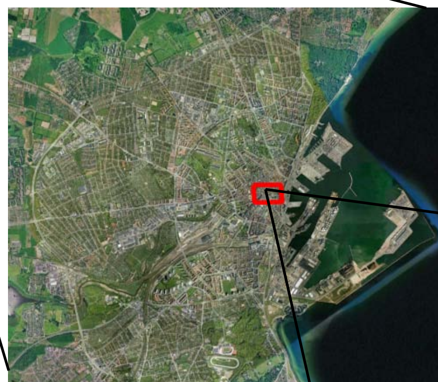
CC= Climate change

These scenarios are added to determine the severity of CC impacts and to give a framework for understanding costs and benefits of adaptation

Example

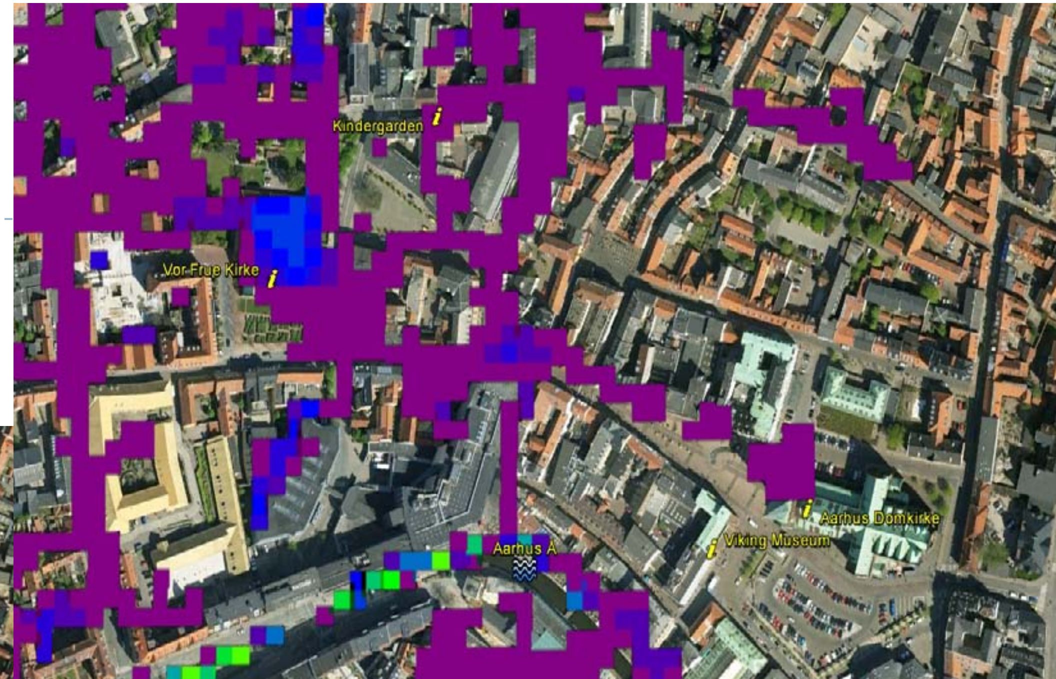
Case Area – Central Århus City

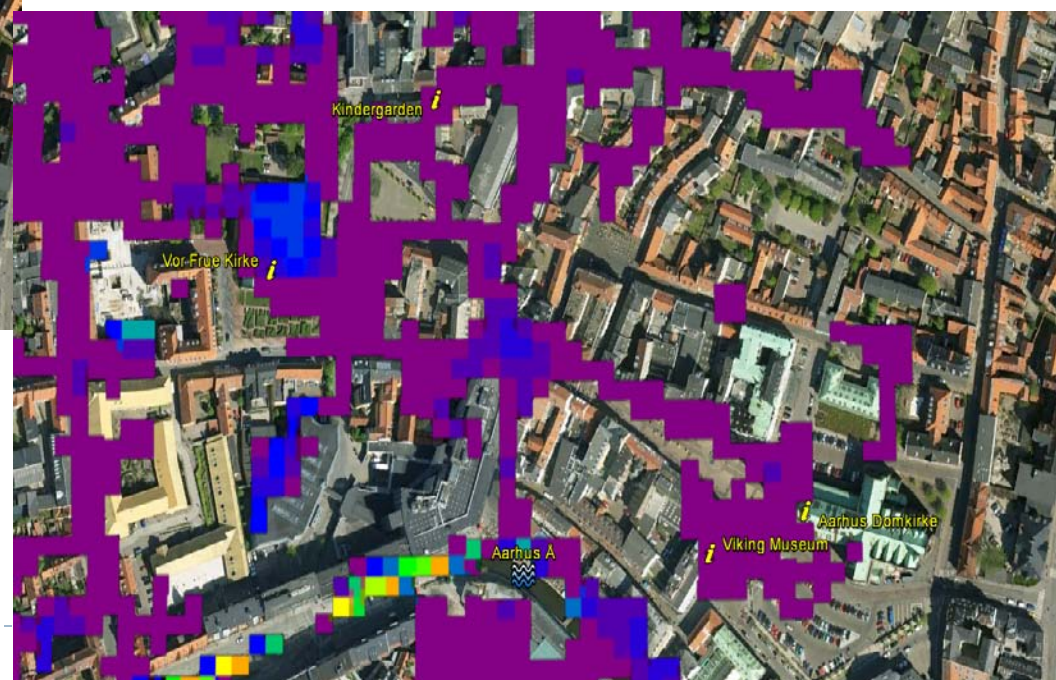
- Vor Frue Church
- Aarhus Cathedral Church
- Viking Museum
- Roads
- Pedestrian streets
- Residential/public buildings
- Shopping



Flooding extent

100 year event with NO CC Reference (O_R)





100 year event with CC (O_0)

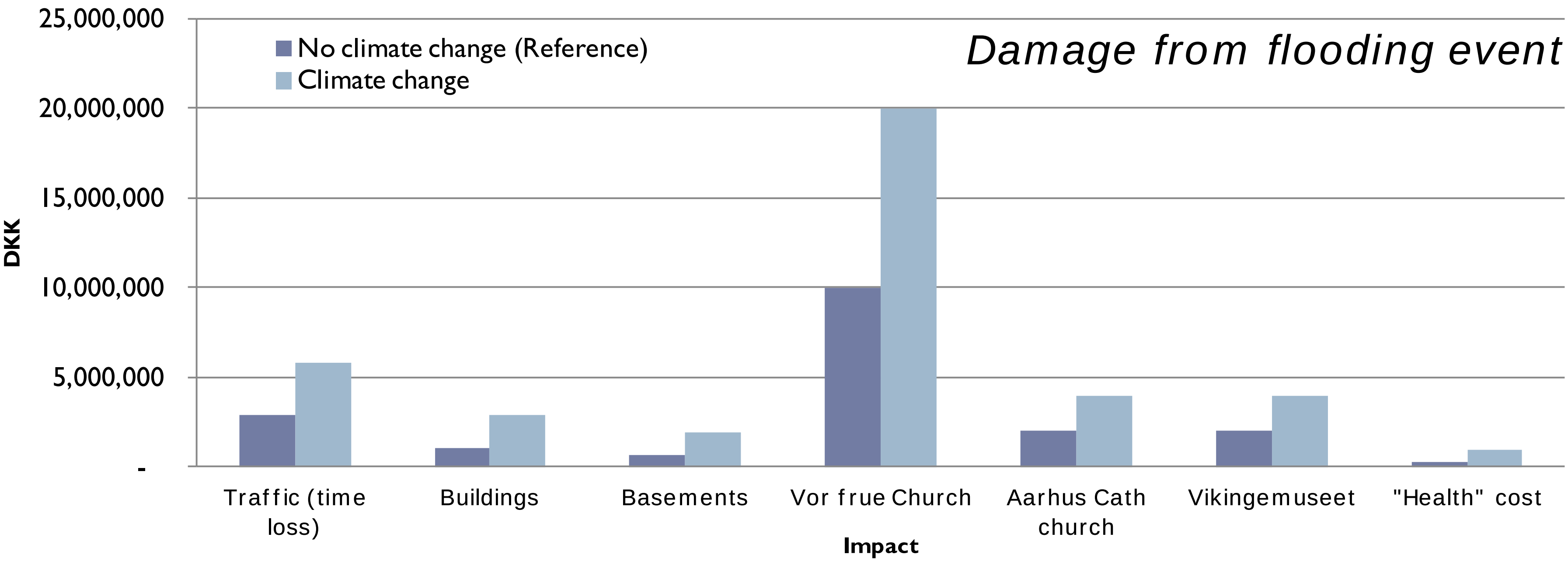
Decomposition of Damage Elements

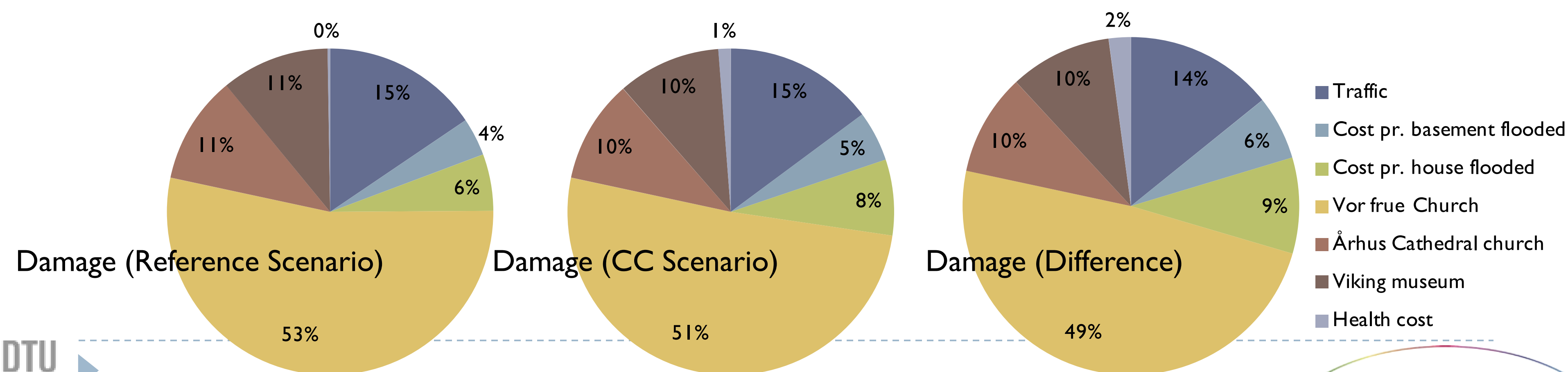
- Alternative preferences create different damage estimates, based on the values of decision maker
  - Buildings: Cost of repair versus willingness to pay for avoiding damage (including all welfare losses by consumers)
  - Historical heritage (repair costs versus intrinsic value)
  - Transportation (cost of lost productivity to the local economy)
  - Children's health (health costs, parents remaining home, social/political value, ethics)

Economic Cost Estimates

Traffic			
Lost time	Low	150	Dkk/hr
	High	150	
Buidlings			
Cost pr. basement flooded	Low	20,000	Dkk
	High	40,000	
Cost pr. house flooded	Low	300,000	
	High	600,000	
Vor frue Church			
Cost of flooding	Low	10,000,000	Dkk
	High	20,000,000	
Århus Cathedral church			
Cost of flooding	Low	2,000,000	Dkk
	High	4,000,000	
Viking museum			
Cost of flooding	Low	2,000,000	Dkk
	High	4,000,000	
Health cost			
Average salary pr. day		1,200	Dkk

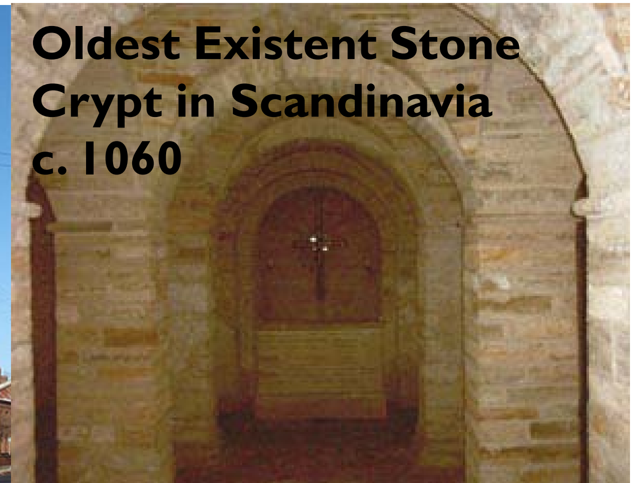
Evaluation of the Impacts





Impacts: How do we weigh these?

Von Frue Kirke:



Oldest Existent Stone Crypt in Scandinavia c. 1060

Viking Museum: Archaeological Site

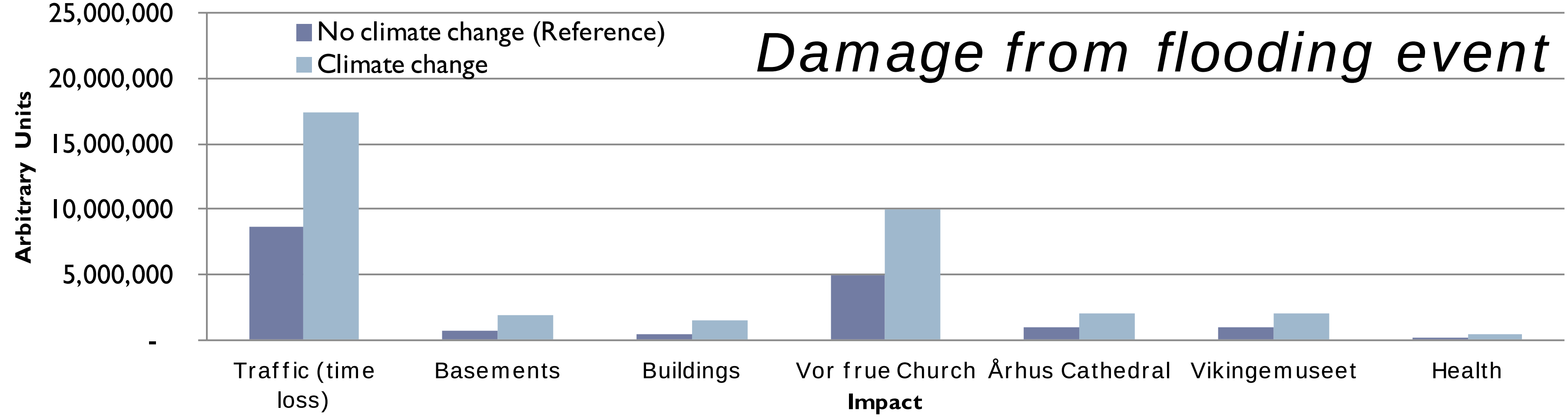
Århus Domkirke:

Numerous Frescos c. 1300-1500

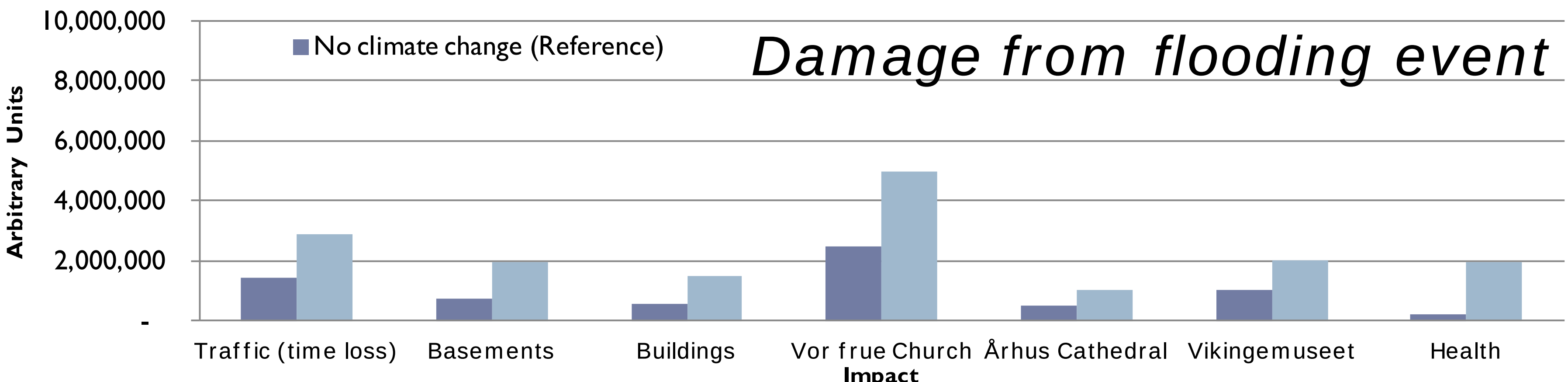
Baroque Organ: Largest Church Organ in DK

Kindergarten: Very new things

Effect of Different Weighting Functions



$W_1(x)$	300%	100%	50%	50%	50%	50%	100%



$W_2(x)$	50%	100%	50%	25%	25%	50%	400%

Uncertainty: Århus in the Future

Århus 2009 municipal plan: ***In the next 20 years:***

- +50,000 jobs
- +10,000-15,000 students
- +75,000 population
- The council has made environmental and social sustainability a priority in it vision for the future.

- How does this affect the analysis of future impacts?
- How does this change the decision making criteria?

Conclusions

- Impact assessment seeks to:
  - quantify the damage to a set of areas that are of concern
  - show the additional impacts anticipated from a changing climate and highlight uncertainties
  - narrow down the list of adaptation options that can best reduce the damage from multiple impact dimensions

CLIMATEDTU

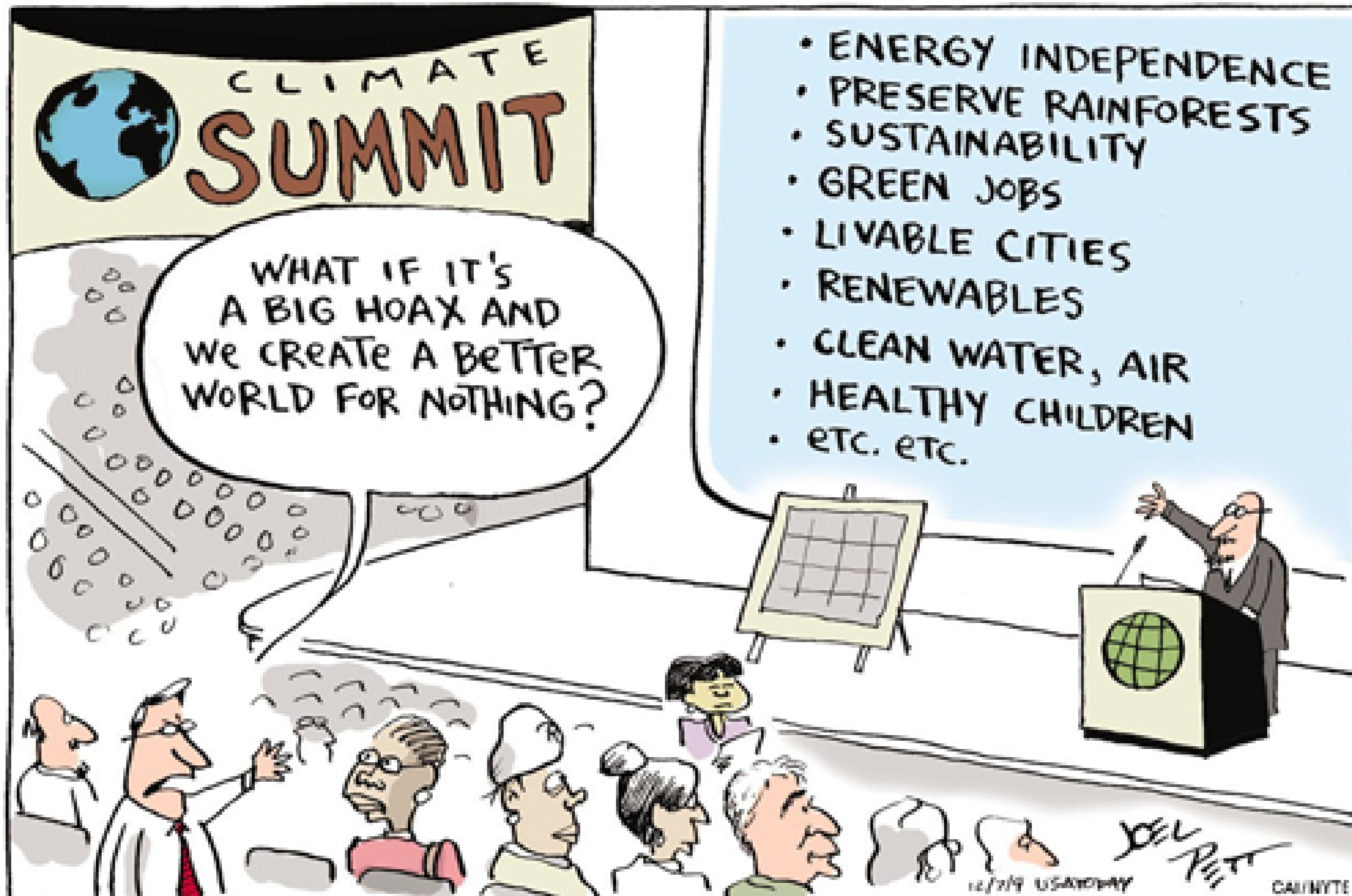
DTUs cross-disciplinary climate platform

The Role of Geography in Climate Change

- Debate:
  - Balling (2000) “The entire global warming/greenhouse issue is perfectly suited to our discipline”
  - Demeritt (2009) We shouldn’t “over-emphasize the unique pedigree and potential of geography as a synthetic environmental science”
  - Smith (2008), Turner (2002), Hobson (2008), Hulme (2008), Hardin (2010), Wainright (2010)...

- meanwhile...

Geographers are doing the research


CLIMATE SUMMIT
WHAT IF IT'S A BIG HOAX AND WE CREATE A BETTER WORLD FOR NOTHING?
• ENERGY INDEPENDENCE
• PRESERVE RAINFORESTS
• SUSTAINABILITY
• GREEN JOBS
• LIVABLE CITIES
• RENEWABLES
• CLEAN WATER, AIR
• HEALTHY CHILDREN
• etc. etc.